G.E.C. Journal

VOL. VI. MAY, 1935. No. 2.

CONTENTS

PAGE

FRONTISPIECE: TRAIN DESCRIBERS – – – – – 66

ROAD SURFACE REFLECTION CHARACTERISTICS AND THEIR INFLUENCE ON STREET LIGHTING PRACTICE – – – 67
By J. M. Waldram.

TRAIN DESCRIBERS – – – – – – – – 87
By F. L. Castle and B. F. Moss.

GENERATION, DISTRIBUTION AND USE OF ELECTRICITY ON BOARD SHIP – – – – – – – – 95
By C. Wallace Saunders, H. W. Wilson and R. G. Jakeman.

AN ELECTRICAL TEST RECORDER – – – – – 107
By G. Chelioti.

THE ELECTRIFICATION OF AN INDIAN TOBACCO FACTORY – 112
By P. S. Jackson.

THE ELECTROMETER TRIODE AND ITS APPLICATIONS – – 118
By G. W. Warren.

Published quarterly by

THE GENERAL ELECTRIC Co., LTD.

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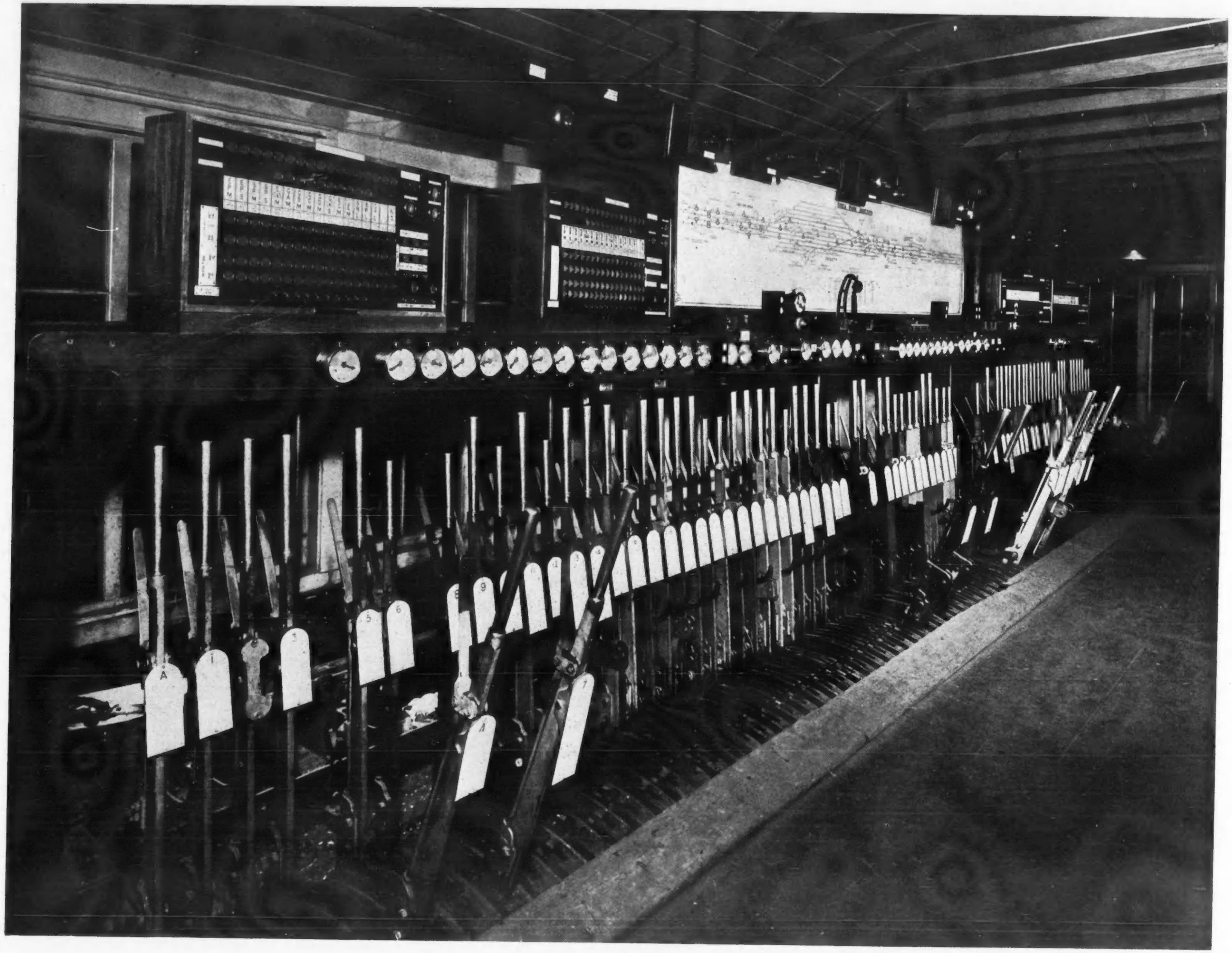


TRAIN DESCRIBERS.

Interior of the signal cabin at Gidea Park Station on the L. & N.E. Railway, showing the train describing equipment installed (see page 87).

G.E.C. Journal

VOL. VI. MAY, 1935. No. 2.

Road Surface Reflection Characteristics and their Influence on Street Lighting Practice*

By J. M. WALDRAM, B.Sc., A.C.G.I., F.Inst.P.
Research Laboratories of The General Electric Company, Ltd., Wembley, England.

Interior of the signal cabin at Gidea Park Station on the L. & N.E. Railway, showing the train describing equipment installed (see page 87).

This article discusses the relation between the appearance of an illuminated road surface, the reflection properties of the surface, and the distribution of light from the light source and its position. Recent work has indicated that the brightness of the road surface is a most important factor in visibility in street lighting, and is of much greater importance than the illumination. New methods of photometry of the brightness of the street surface are described, and data are given of the reflection properties of a two-coat asphalt surface. Methods are given for predicting the brightness distribution over the surface of the road. The effects of considerations of brightness are discussed as regards the design of installations, the design of lighting equipment, and the desirable characteristics of road surfaces.

(1) INTRODUCTION.

LORD KELVIN, we are told, used to say: "When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of 'Science,' whatever the matter may be."

It is quite understandable, after such an observation, that some of those best qualified to speak about street lighting call it the "art of street lighting." For the real quality and essence of street lighting have persistently escaped measurement. Certainly, we measure what we can, such as the illumination on the road surface and the height of the posts, and sometimes achieve great complication thereby; but we have not measured the excellence of the installation. Our knowledge is of a meagre and unsatisfactory kind; street lighting is not yet a science.

The reason is that the criterion of excellence of an installation must be related to the appearance of the lighted street, using the word "appearance" in a broad sense; and it is a commonplace that the appearance of the street as the motorist or the Watch Committee finally sees it bears no recognisable relation to the installation as it was planned by the engineer, with the aid of an ordnance map and curves of intensity distribution.

Qualitatively, we know something about the problem. It will probably be generally agreed that the requirement of an effective system of street lighting is this, that the observer should feel confident of seeing clearly any object of material size up to a considerable distance, without any discomfort due to glare. It is also generally recognised and agreed that objects are seen on a street on practically every occasion by silhouette as dark objects against a bright background, and that the important matter in

* Paper presented at the Eleventh Annual meeting and Conference of the Association of Public Lighting Engineers, held in Aberdeen. September 17 to 20, 1934.

visibility and in good appearance is therefore the brightness of the surface. We know by experience that carefully-placed sources and certain distributions of light can be made to conspire with the peculiarities of some road surfaces to produce a high brightness with a fairly even distribution, against which anything can be seen, and to keep small the dark areas in which dangers may lurk unnoticed. We know that sources ought to be fairly high, and on

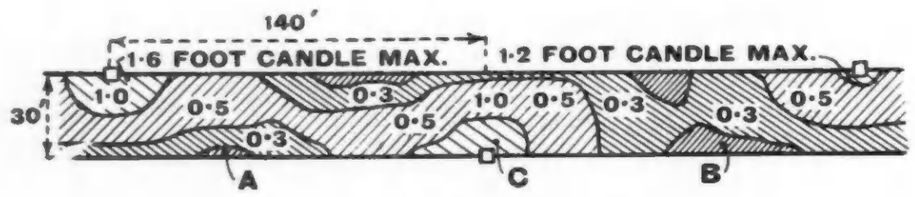


Fig. 1.—Iso-foot candle plan of an installation.

the outside of curves; and we have various views about central suspension. But we have not yet been able to measure these things, nor express them in numbers; neither have we the data on which they can be designed from first principles.

The purpose of this paper is to explore quantitatively the connecting link between the street as planned and the street as seen, and to provide, if possible, some photometric measurement and geometric tools to enable the lighting engineer to predict more nearly the appearance of the installation. It should be emphasised at the outset that the paper is the record of a partly completed research, which has not yet progressed very far; and it will have no

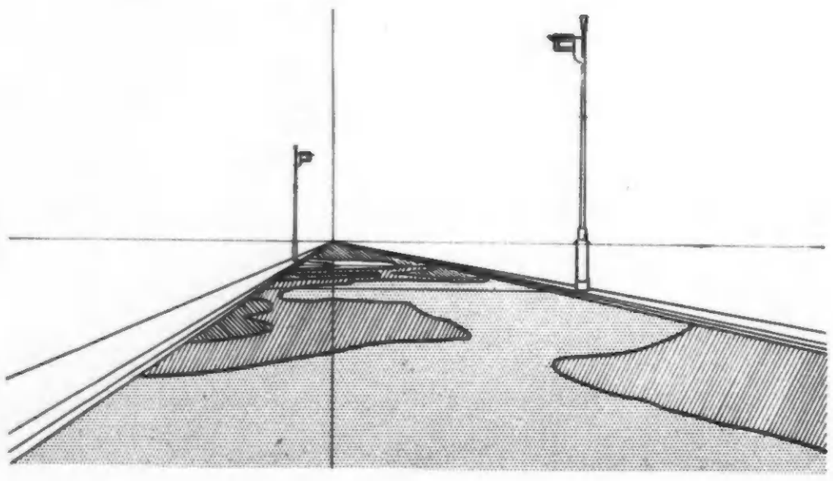


Fig. 2.—Iso-foot candle diagram in perspective projection.

answer yet to a great many problems. Later work may modify its conclusions. It is hoped, however, that the discussion will bring both criticism and guidance for future work.

(2) THE TWO MAIN FACTORS.

Two factors are responsible for the difference between the street as planned and the street as seen. One, the reflection characteristics of the street surface, has been recognised for many years, and much has been written about it.† But although qualitatively many of the consequences of the peculiar properties of road surfaces are known, quantitative data are very meagre, and their application to design is very difficult.

The second factor is equally important, but has been less recognised; nevertheless, it must be considered step by step with the reflection properties if confusion is to be avoided. This factor is perspective. We have much less excuse for failing to consider perspective than reflection properties, for it is purely geometrical; and it has a most powerful effect upon the appearance of a road. It is intimately related to the surface reflection characteristics, and its consideration has led to a great deal of simplification of the problem. No excuse will, therefore, be offered for its discussion at some length, although it has been omitted from an over-long title.

Let us first consider an example of the effects of these two factors. Fig. 1 is the iso-foot candle plan of a section of roadway, determined by experiment. It may be taken as representing the street as planned. If now this section is drawn in perspective, as seen by a motorist opposite to the left-hand post in fig. 1, the appearance will be as shown in fig. 2. This indicates the peculiar effects which perspective produces. The first span occupies, in the perspective view, the region from the line, drawn across the road by the first post, to infinity. The second span, however, although equally important on plan, occupies a space in the perspective as printed of only a sixteenth of an inch in height; and the whole of the rest of the road—supposing it to be level and straight—a further eighth of an inch in height. All the detail of the distribution in the second and further spans is cramped beyond recognition.

If now the effect of surface reflection is included in addition, the result is shown in fig. 3, which is from a photograph of the installation in question. (A slight hill has disturbed the simple perspective shown in fig. 2.) A comparison of the three figures will indicate the complete havoc which has been made of the plan of fig. 1 by the simultaneous operation of surface reflection and perspective.

Let us briefly note the general characteristics of the appearance of the road surface as shown in fig. 3 when lighted by a single unit. Where any notable degree of polish exists the brightness of the road surface beyond the post is very low, particularly when the road surface is dark in colour. In this region objects can be quite invisible, because they have a very dark background. But on the side nearer to the observer a bright patch or streak is formed, the centre line of which always runs directly towards the observer, and which extends over very long distances on the road surface. It often happens that a single source will produce a bright streak

† Preston Millar. Trans. Ill. Eng. Soc. (Amer.), 1910, p. 653: 1916, p. 479. Stewart, A.P.L.E., 1924. Waldram, A.P.L.E., 1928. Langlands, Proc. Municipal and County Engineers, 1932. Waldram, Roy. Soc. Arts., J., February 9, 1934, p. 331.

several hundred feet in length. Near the post the streak becomes wider and the complete streak often has the appearance of a T or inverted L.

These bright patches have not really a sharply defined edge, but where the brightness falls off to a low value they cease to form an effective background ; and this limit is fairly easily seen.

The superimposition of several of these streaks forms the brightness distribution on the road surface; and it is with their formation, size, and position, that this paper is concerned.

Now the chief function of public lighting nowadays is to enable the vehicle driver to see the pedestrian and other objects in the carriageway, and the pedestrian to see the vehicles approaching him. Of these two individuals the driver is the more important, at least in so far as his requirements are the more difficult to meet ; and the driver is particularly concerned with these long bright streaks. For a driver sees objects on a lighted road by silhouette against the bright surface,* and he generally drives looking at the road some 300 feet ahead. He is not usually very concerned with objects within the span in which he may be driving, although he is close to them ; for having seen them some distance before, he has set his course and speed to avoid them, and is now concerned in judging the traffic about three spans ahead, in order to determine his further course and speed. If, therefore, he is to see objects 300 feet away, he will see them against the street surface at a greater distance, and that surface will appear bright only by reason of streaks formed by still more distant sources. Any source between the driver and the object cannot contribute to the background against which the object is seen. Therefore the contribution to the surface brightness made by sources 400 to 600 feet distant is a most important feature, and more important to the motorist than that from the nearest posts.†

On the other hand, the pedestrian, although concerned with a distant view of fast moving traffic, is much more concerned with near objects ; and he requires illumination as such in the span in which he happens to be, in order to see the kerb, or obstructions, or the numbers of houses.

The streaks are formed as the result of the way in which the light is reflected from the road surface. If this were matt, its brightness would be the same in all directions of view. If it were polished as a mirror the incident light would leave the road surface only in directions defined by the laws of reflection, and the result would be a clear mirror image of the light source, lying apparently below the surface.

But the surfaces used in practice all possess some degree of partial polish ; they are neither matt nor specular, but have intermediate properties which have been called "spread" reflection characteristics. Light leaves such surfaces mainly, but not entirely, in preferred directions not far from the direction in which specular reflection would take place.

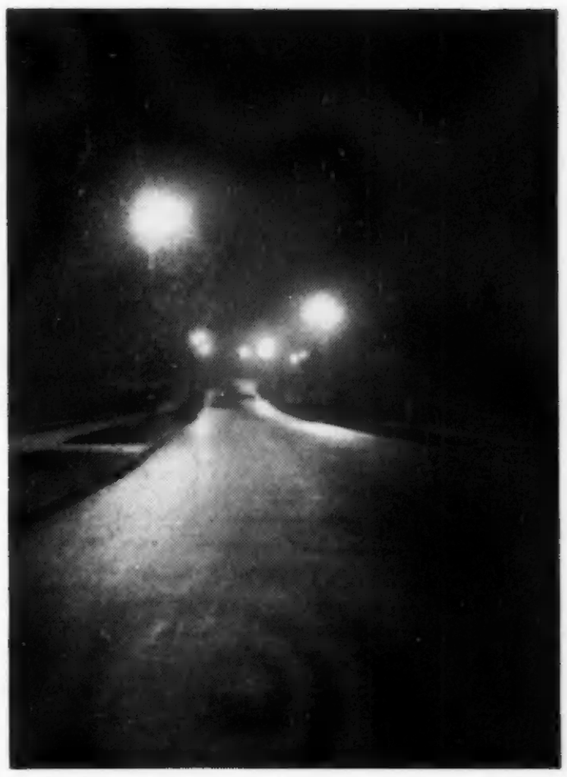


Fig. 3.—The actual lighting installation of which figs. 1 and 2 are iso-foot candle diagrams.

As the observer views the street, those parts which reflect light in his direction appear bright, their brightness depending upon the amount of light falling upon them, and their preference for reflecting it in his particular direction. The peculiar shape of the streak is an index of the various degrees of preference which exist in different directions. For example, it runs directly towards the observer, because the surface prefers to reflect mostly in the plane of incidence, as a mirror ; it is narrow because that preference is marked, and little light is reflected in other planes.

(3) GEOMETRICAL PROBLEMS.

Before the methods of measuring brightness and reflectivity can be described, it will be necessary to explore, as briefly as possible, some of the geometry of the appearance of the street.

(a) Perspective.

A perspective view is a geometrical projection with certain quite definite properties, which can be usefully turned to account. Let us, without going deeply into perspective geometry, observe a few of its characteristics.*

* Waldram, A.P.L.E., 1928. Preston Millar, I.E.S., 1928, p. 1051.

† Péri has suggested that the vision of a moving observer, such as a motorist, differs from that of a stationary observer in that he looks at a fixed distance ahead, and r is thereore constant (see paragraph 3 (b)). This is probably incorrect. Each sees the whole of the perspective in just the same way, though the motorist concentrates upon objects at about 300 feet away. In each case the gaze shifts from one point to another, and momentarily holds the image of that point steady on the retina.

M. D. Vernon, Med. Res. Council. Reports of Committee. "Physiology of Vision.—VIII." (H.M. Stationery Office). Péri : l'Ellectrotecnica, 1923, p. 263.

* For further notes on the subject, see Waldram, P. J., and J. M., R.I.B.A. Jour., XL., Ser. III, No. 15, p. 609, June 17, 1933.
Waldram, P. J., R.I.B.A. Jour., XLI., p. 509, March 27, 1934.

The construction of a perspective projection may be seen from fig. 4.

Let ABCD be a solid object, and let P be the eye of an observer. If M is a plane, transparent, but capable of being drawn upon, and if the observer

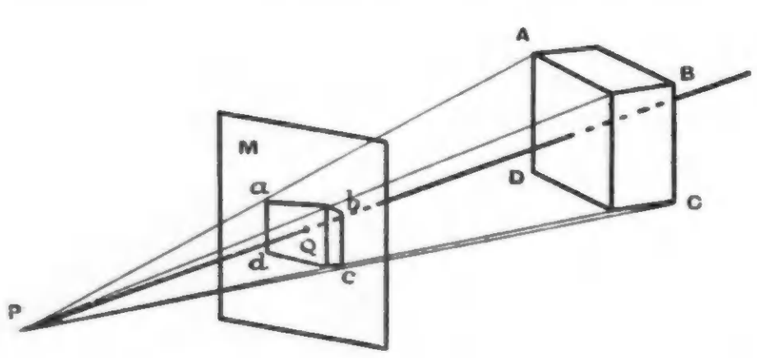


Fig. 4.—Illustrating construction of a perspective projection.

traces upon M the outline *abcd* of ABCD, each point on the trace being in line with his eye and the corresponding point on the object, then *abcd* is a perspective projection of ABCD. In other words, *abcd* is a projection of ABCD upon the plane M by straight lines passing through P. A photograph is a perspective projection, the point P being in the lens of the camera. The line PQ through P and normal to M is the axis of perspective, and Q is the centre of perspective. The length PQ is the perspective distance, or, in the case of a photograph, the focal length of the camera lens.

Evidently, if a perspective projection of an object is made, and is viewed from the point P, from which it is drawn, then the view of the perspective will correspond in all geometrical respects with that of the original object: the angles subtended at the eye by parts of the perspective will be the same as those subtended by corresponding parts of the original

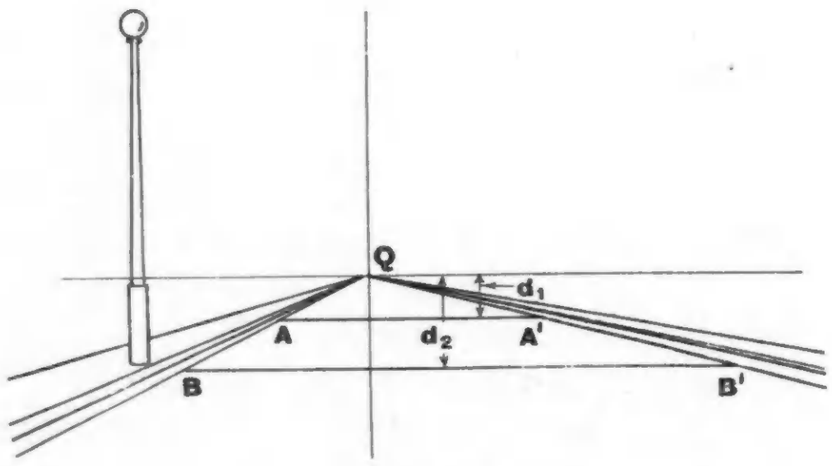


Fig. 5.

object. A perspective properly represents the object as seen.

It is easy to show that:

(1) The perspective projection of any vertical straight line is a vertical straight line (if M is vertical) and the projection of any horizontal straight line *which is parallel to M* is a horizontal straight line; and

(2) The projection of any system of parallel straight lines, *not* parallel to M, is a series of straight lines converging to a point known as a vanishing point. If the series of lines is horizontal, the vanishing point will lie on a horizontal line through Q, and if the series of lines is parallel to PQ, then Q is the vanishing point. For instance, in fig. 5, the posts appear as vertical lines, and lines drawn across the road are horizontal lines; but the edges of the kerbs and paths appear as lines converging to the centre of perspective.

(3) A horizontal line on the surface of the road running directly towards the observer appears on the perspective as a vertical line.

It can also be shown easily that the scale of distances measured parallel to PQ is an inverse one: *e.g.*, in fig. 5 if A is the perspective projection of a point which is D feet from the observer, on the kerb of a road, then the intercept d_1, measured vertically, will be proportional to 1/D. Along any line such as AA′, however (representing a line parallel to the plane of perspective M), the scale of distances in the projection is a linear one, although the scale at AA′ will be smaller than that at, say, BB′ in the ratio of d_1 to d_2 in the figure.

It is also evidently quite easy to place upon a perspective chart a scale of angles, for the position of objects in the perspective is obviously defined by angles measured at the eye. A series of horizontal*

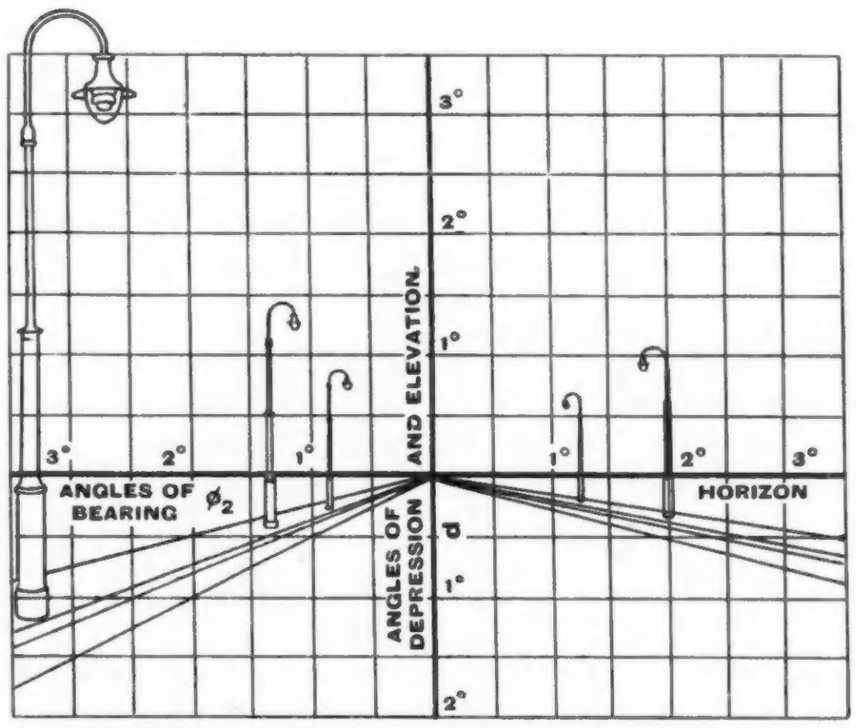


Fig. 6.—Angular scales on perspective.

and vertical lines can thus be placed on the perspective indicating angles of elevation or depression (d) and bearing (ϕ_2), so as to form a frame of reference for the perspective (see fig. 6.) The distance of a line representing an angle d or ϕ_2 from the axis is given by PQ tan d or PQ tan ϕ_2.

* The lines indicating elevation are not strictly straight, but form a series of hyperbolae. Within the range dealt with in this paper, they can, however, be considered as straight and equally spaced, without serious error.

This means that any perspective view, such as a photograph, is in itself a record of angles of bearing and elevation of objects as seen from an observer's eye, or from the position of the camera.

The first requirement in designing an installation as it will be seen, rather than as generally planned, will be to portray it as it will be seen in perspective. The step from a plan to a perspective is really quite easy, and to facilitate the operation fig. 7 has been prepared.

This figure is simply the perspective view from a height of five feet (the average height of a driver's or a pedestrian's eye) of a web of lines drawn at right angles to one another on a horizontal plane passing through the observer's feet, which will be termed the reference plane. One set of lines, which is arranged along the general direction of the street and parallel to the direction of view, is at 1 foot spacing, and the other set consists of lines drawn at right angles to them at various convenient distances from the observer. There is also shown a vertical scale, which can be taken to be drawn on a post at a distance of 200 feet away and 10 feet left of the line of sight.

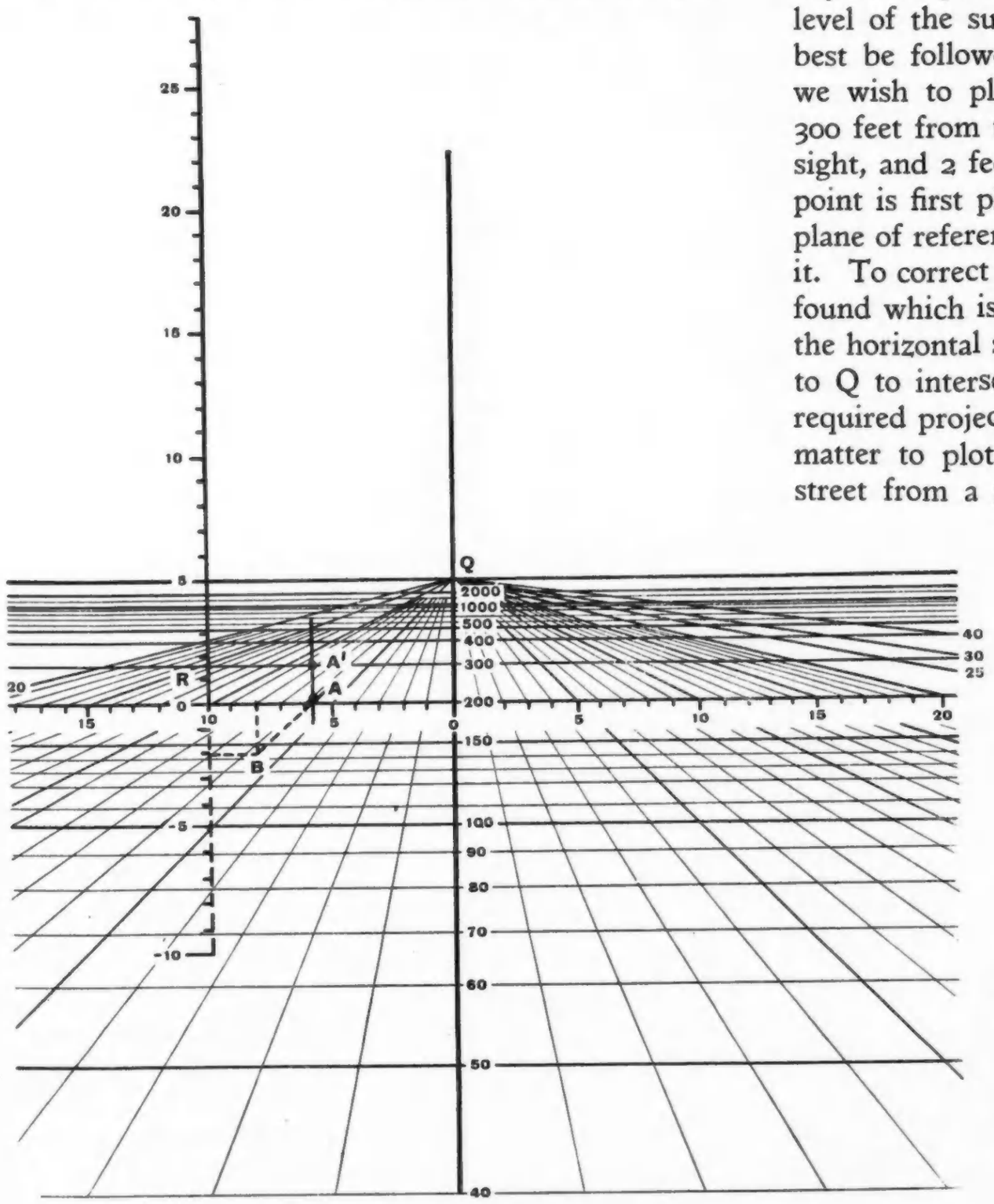


Fig. 7.—Perspective plotting web.
(Drawn for perspective distance of 57.5 cms.)

The scale of height is also carried down below the reference plane. Although this scale is correct only for objects at 200 feet from the observer, it can be easily made to apply to any other distance, as will be shown. The scale of distances at right angles to the line of sight is marked on a line through the foot of the post R, and is identical, on that line, with the scale of heights. On this web of lines the perspective view of the street can be plotted directly.

Suppose that a plan of the highway exists giving the kerbs, buildings, and proposed lighting fittings, and also particulars of levels, etc., as in fig. 28, page 83.

Suppose that a point of view has been chosen from experience, or otherwise, as one from which visibility is likely to be poor. Let a line of sight along the street be drawn, and let offsets be taken from this line to the edges of the kerbs and to any other point which it is required to plot. If the road is level the perspective can at once be plotted on fig. 7 by these offsets.

If the road is not level, or if it is required to plot any other point, such as a light source, not on the level of the surface of the road, the procedure can best be followed by way of an example. Suppose we wish to plot a point on the kerb A, which is 300 feet from the observer, 8 feet left of the line of sight, and 2 feet below the plane of reference. The point is first plotted at A′ as though it were on the plane of reference, and a vertical line drawn through it. To correct for the change in height, a point B is found which is 2 feet below R, and at 8 feet left on the horizontal scale through R. This point is joined to Q to intersect the vertical through A′ at A, the required projection of the point. It is thus a simple matter to plot the perspective of quite a complex street from a given viewpoint. Fig. 29 shows the perspective of fig. 28 as seen from P, fig. 28.

(b) Geometry of Installation.

Now let us consider the geometry of the formation of a "streak" in the perspective view.

In fig. 8, let S be the light source and P be the observer's eye. Let the distance of the observer from the post be D. Suppose that the observer is looking at a point X on the road surface, X being not on the line AB. Light will then be emitted from the lantern at S, fall upon X, and be reflected to P, the brightness of X being dependent upon the amount of light falling upon it from S, and the amount which the surface reflects in the direction of P.

Now the appearance of the street surface to the observer at P consists of a pattern of points, such as X, of different brightnesses, arranged at various positions in his field of view, which are defined by

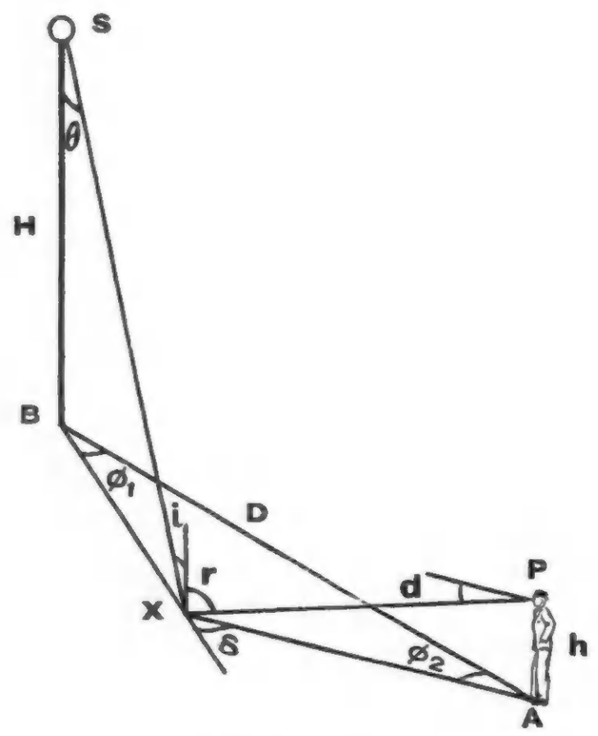


Fig. 8.

the angles *d* and ϕ_2, in the figure. These angles are the angles of bearing and depression which are drawn on the perspective of fig. 6. If we can find the brightness of the surface for each value of *d* and ϕ_2, we know the appearance of the street.

Now let us consider the point on the road, X. The reflectivity at X will vary with the angle of incidence, *i*, the angle of reflection, *r*, and also with the angle of deviation, δ, since X is not on the line AB, and the incident and reflected rays are not in the same vertical plane.

Finally, the light reaching the point X from S will depend upon the light distribution of the lighting

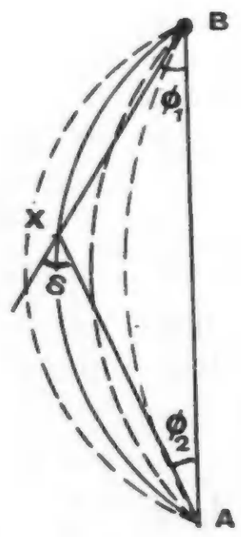


Fig. 9.

fitting, and will depend upon the two angles, θ and ϕ_1, the angles which are the basis of the polar distribution of the lighting fitting.

These seven angles are all related to one another by the geometry of the installation, and a great deal can be learned immediately from the relationships which exist between them. Let us consider first the angles measured in horizontal planes. Obviously, by simple geometry, $\delta = \phi_1 + \phi_2$ (fig. 9); and if X moves on the road surface, so that δ is constant, it will move on a circle through A and B. In plan, lines of constant δ will be a series of such circles. If, now, we plot these circles in perspective as they would appear to the observer, they will appear as in fig. 10.

Now it is evident, from observation of streets, that the reflectivity of the street surface varies very rapidly with the deviation δ, falling off rapidly as δ increases. This is the reason for the formation of the bright streaks which characterise the appearance of all polished road surfaces. The shape of the lines of equal δ in fig. 10 supports this observation, for they follow approximately the shape of the streak at least at its lower end. This is later confirmed by experimental results.

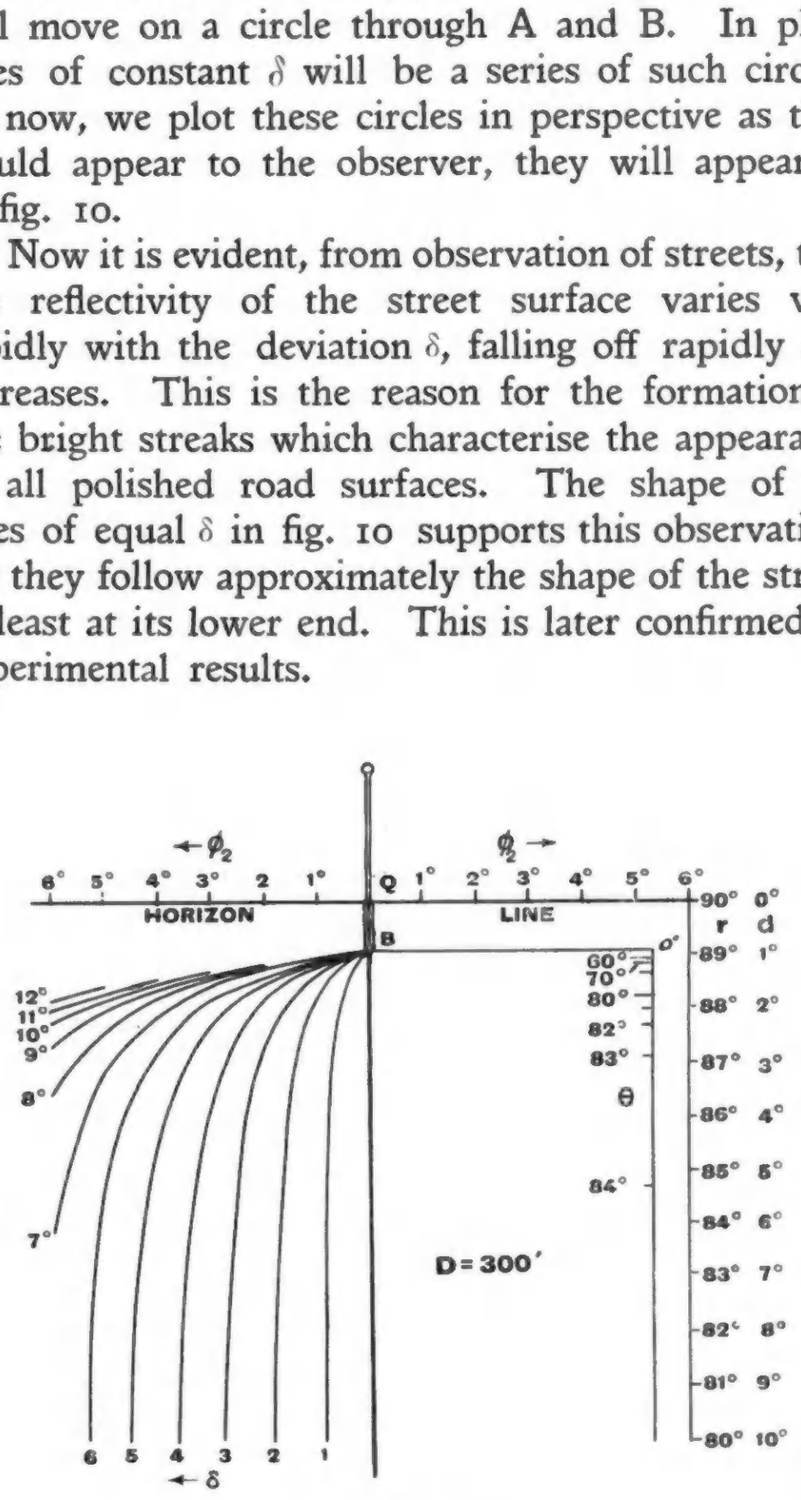


Fig. 10.

Now let us consider the angles measured in vertical planes. It is obvious, from fig. 8, that $\theta = i$; and $r = 90 - d$. That is, the vertical angle in the polar curve is equal to the angle of incidence on the street surface, and the angle of reflection from the street surface is equal to the complement of the angle of depression in the perspective. In fact, if in the perspective we measure *d* from the vertical instead of from the horizontal, the scale of *d* on the perspective will be a scale of *r*. It is so marked in fig. 10 at the side. Now there is obviously a relation between *i* and *r*, depending on the heights of the observer and the light sources and the distance D. This is easily shown to be

$$\tan i = \frac{D - h \tan r}{H} \quad \ldots\ldots\ldots \quad (1)$$

where *h* is the height of the observer and H that of the light source above the surface. If we plot the

variation of i with r, for various values of D, as in fig. 11,* we find that for large values of r, (*i.e.*, for points in the view near the foot of the post,) i varies very rapidly; but for smaller values of r, i becomes almost constant. (This can be followed from fig. 8.) Now i is the same as θ, the angle taken from the polar curve, and r is the angle of depression in the perspective. Therefore, with the help of fig. 11, we can place on any perspective yet another scale, giving the values of θ from the polar curve which correspond to each point in the perspective.

We now discover that for viewpoints at a reasonable distance from the source, the greater part of the field of view is served by a very small region of the polar distribution.

At 200 feet distance, with a source height of 25 feet, almost the whole of the field of view is served by the part of the polar curve from 75° to 82°. Fig. 11 shows also that as the distance of the observer from the post increases, so the region of the polar curve which serves the major portion of the field of view becomes narrower, and lies at a greater angle with the vertical. The effective regions of the polar curve are as follows:—

TABLE 1.

Distance from Post	Effective Region of Polar Distribution.	
	Height of source, 25 feet.	Height of source, 13 feet.
200 feet	75° —82°	81° —84°
300 ,,	82° —84½°	86° —87°
400 ,,	84½°—86½°	87° —88°
500 ,,	86° —87°	88° —88½°

This indicates an important characteristic of the polar distribution. In some forms of street-lighting fitting the intensity is arranged to be cut off at about 78°-80°, or, at least, to diminish greatly in value, in order to reduce glare and increase efficiency. While this does reduce glare, it also has the effect of reducing the brightness produced by the more distant light sources and materially shortening the streaks which they form. The usefulness of intensity emitted above the "peak" or angle of maximum intensity has been discussed at length in the technical press,† and the geometry of the installation thus gives a large part of the answer.

The height of the post alters the relationship between i and r. It will be seen from equation (1) that a variation in H produces an inverse change in the tangent of i. Therefore, if, as in fig. 11, we use for the scale of i a scale of logarithmic tangents, and if this scale is movable along its length against a logarithmic scale of heights, then the i/r relationships, which were plotted for a height of 25 feet, can be made to apply to any mounting height. The height of the observer is retained constant at 5 feet from the ground.

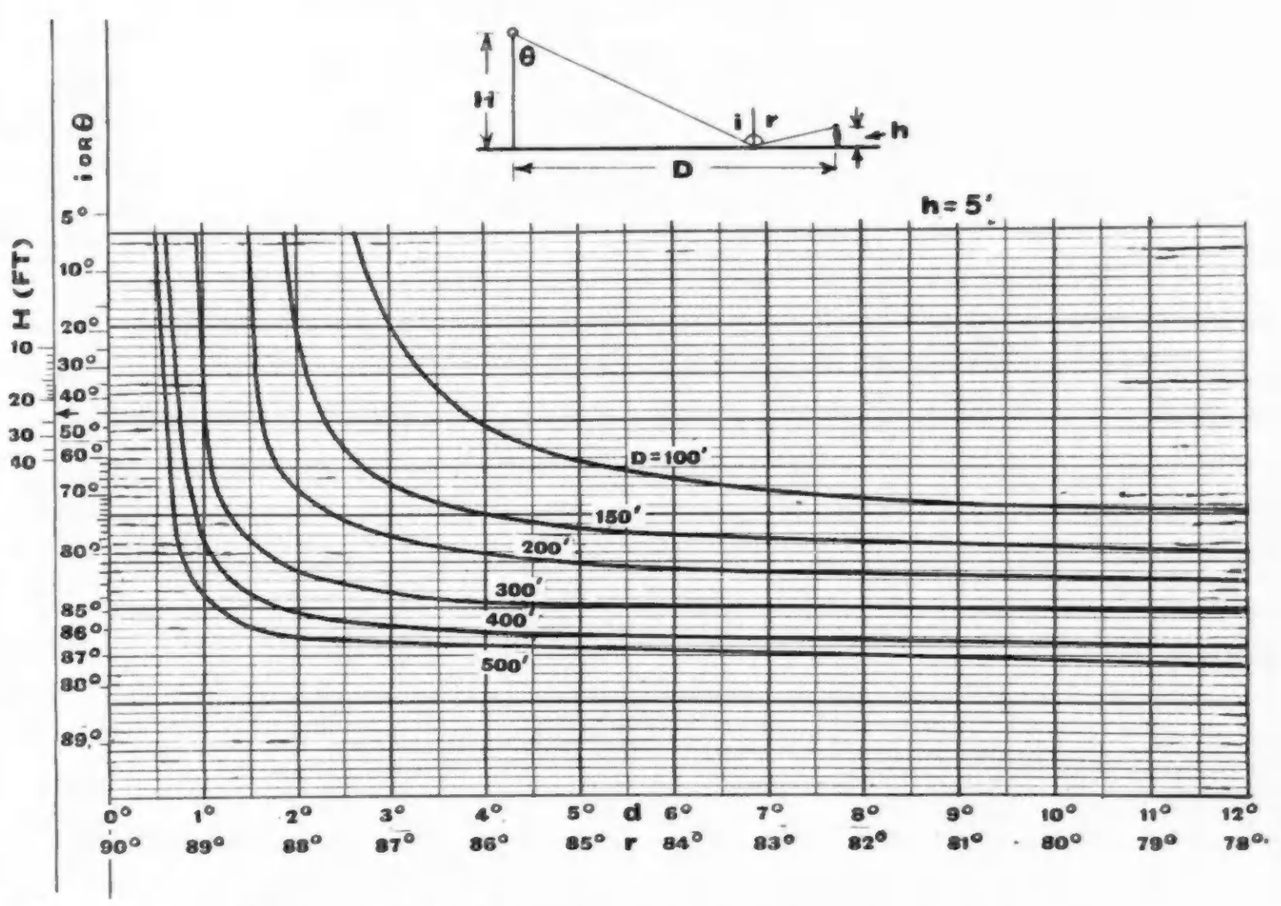


Fig. 11.—Calculating chart relating i, r, H and D.

This diagram relates, strictly, only to the line joining the observer and the light source, but since we shall be concerned only with small values of δ—say, up to 8°—it can be applied without material error to points on the road surface not on this line.

(4) MEASUREMENTS OF SURFACE BRIGHTNESS AND REFLECTIVITY.

(a) General.

Geometrical considerations can take us only a certain distance, and really form only the starting-point for experimental work. Before we can get any further we must know how bright any given spot on the road will appear under given geometrical conditions and values of illumination.

Several attempts have been made to determine the reflectivity of road-surfacing materials. Péri* made measurements of brightness on three types of road surface, both wet and dry, but his measurements were confined to the centre line of a road lighted by central suspension, in which all the streaks are superimposed. Preston Millar†, in 1928, made certain road-brightness measurements with a photometer having a restricted field, and published photographs having isolated brightness measurements marked on

* In fig. 11, the angle of depression d has been plotted instead of r, for convenience; since this is equivalent to reversing the scale of r, the scale of i has been also reversed.

† Ill. Eng., Dec., 1933, pp. 315-6.

* l'Ellectroctecnica, 1928, p. 263.

† Ill. Eng. Soc. Trans. (Amer.), 1928, p. 1051.

them ; also brightness measurements in actual streets made with a constant value of r. A more thorough exploration was made by Taylor ‡ at the National Physical Laboratory, using slabs of material taken from actual roads, illuminated by a large lamp, and viewed with a Macbeth photometer at various angles. These data are much more complete, but apply only to the centre line of the streak, where $\delta = 0$. At the present time work is being carried out by Cohu at the Société pour le Perfectionnement de l'Eclairage,* using the same general method, but much more

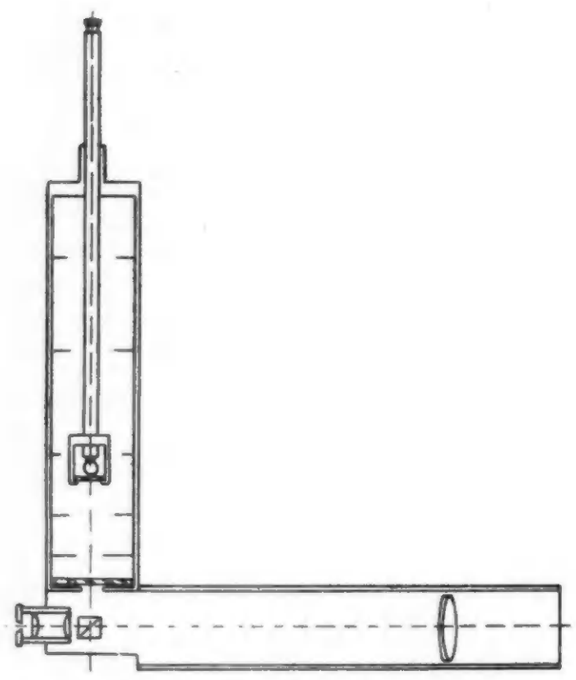


Fig. 12.—Optical elements of telephotometer (Diagrammatic).

elaborate apparatus, and using a photoelectric cell as the photometric element. This work will include measurements made at oblique angles.

M. Cohu's apparatus is necessarily large and costly, and involves the use of a large room. But not the least part of such experimental work is the portrayal and use of the results. It has been seen that the reflectivity of the surface varies with each of the three angles i, r, and δ ; so that a complete statement of the properties of any surface must require a family of solid polar curves, like iso-candle curves, or their equivalent. Having obtained these curves, their use in a given problem is not less complex unless the geometry of the problem is very thoroughly grasped ; and simplification is not easy.

For two reasons—cost and complication—the measurements which are to be described have followed a different line. Methods have been devised of measuring reflectivity *in situ* from the light of an existing installation, and of so handling the results that they can be fairly easily interpreted and used.

The method is based upon fig. 11. Any point on this diagram corresponds to some particular values of i and r, so that (neglecting δ for a moment), it is possible to plot on this diagram a series of contour lines, joining points at which the reflectivity ρ is the same. If such contours are drawn on tracing paper and laid over fig. 11, with the scale of i corresponding to that on the slide in fig. 11, then the curves of fig. 11 will pick out from the contours the values of ρ appropriate to a source of any given mounting height, as determined by the setting of the slide, at a distance D corresponding to the particular curve used. One sheet can be prepared for each relevant value of δ, and if a perspective view is prepared for the given viewpoint, showing the δ lines, the values of brightness can be calculated and plotted along the δ lines on the perspective. From this the complete brightness distribution in the perspective view can be built up. (See figs. 19-23.)

In order to obtain the data, it is sufficient to determine the reflectivity, for each point on the road surface, when viewed at the distances corresponding to the curves of fig. 10, viz., 100′, 150′, 200′, 300′, 400′, and 500′. Each of these determinations enables points of known reflectivity to be marked along one of the curves, and from the whole set of six determinations the family of contours can be plotted.

(b) Experimental Methods.

(*i*) *Telephotometer.*

The necessary experimental work consists in setting up, at the known distance from a single source, and at a height of 5 feet, an instrument

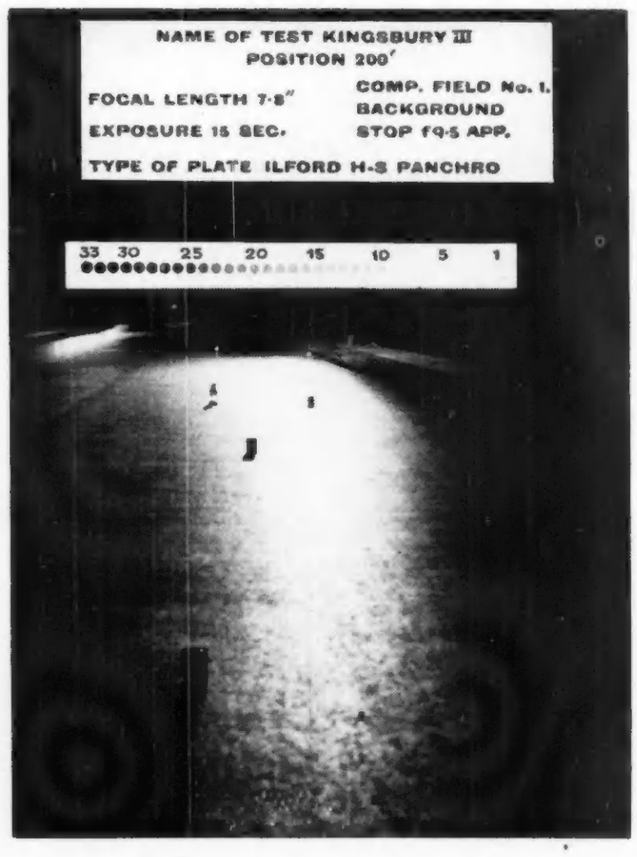


Fig. 13.—Reproduction of a print from a typical plate.

capable of measuring the road surface brightness, and determining the brightness at a sufficient number of points at each station, in the same general way as that adopted by Millar and by Péri. Measurement must also be made of illumination in order to calculate the reflectivity.

The first instrument used for this purpose was a telephotometer (fig. 12) built for the purpose.

‡ I.C.I., 1928, Comptes Rendus, p. 49. D.S.I.R. Illum. Res. Cttee., Tech. Paper No. 9.

* Révue Générale de l'Electricité, XXXV., pp. 147-155, Feb. 3, 1934.

This instrument was designed originally for use in models, and consists of a small telescope with a magnification of about 10, having a very small prismatic photometer field at its focus. The observer sees a telescope image of the street surface, in which appears a small rectangle having a central horizontal slit. This rectangle is illuminated to a known brightness by a photometer system similar to that of the Macbeth photometer, and a balance is obtained when the brightness of the road seen through the slit is equal to that of the surrounding rectangle. The angular width of the slit is about $1\frac{1}{2}$ minutes of arc, and the actual size of the patch of silvering which constitutes the rectangle is about $\frac{3}{4}$ mm. $\times$ $\frac{1}{2}$ mm. Making this field is a rather delicate operation.

The instrument is carried on a tripod having slow motion adjustments. It is believed to be one of the smallest telephotometers so far produced, and the only one suitable for model work. The writer hopes to publish a more detailed description elsewhere.

(*ii*) *Photographic Method.*

While the telephotometer is excellent for the measurement of brightness at a few positions, for the purpose considered its use is lengthy and tiring. The obtaining of the data required by the above method with the telephotometer would need several complete nights' work on the road, and, moreover, involves several experimental inconveniences, not least of which is the measurement of the angles concerned. In the course of the work another method suggested itself, which has proved much more convenient, and agrees well with results obtained with the telephotometer. Reference has already been made to the value of the perspective, inasmuch as it is possible to obtain from it all the angles concerned. The most straightforward method of obtaining a perspective is to take a photograph. If the photograph can be made to produce a quantitative measure of brightness as well, a much more convenient record is available of the surface brightness of the street. Experience has led most street-lighting engineers to disbelieve all photographs of installations except their own. It may come as a welcome surprise, therefore, to hear that a street-lighting photograph has, it may be for the first time on record, been made to tell the truth.

It is hoped that the method may be described in more detail on another occasion, when more results are available, but it is, briefly, as follows :—

A camera is set up at the appropriate position and a photograph taken of the street surface only. The part of the plate on which the image of the light sources would fall is covered, and the sources themselves are screened so that no direct light from them falls on the lens. All trouble from lens flare and halation is thus avoided. Afterwards, in the laboratory, the cover over the lower part of the plate is removed, and a photograph is taken on the same plate with the same camera, exposure and stop, using only the lower part of the plate which was previously covered, of a series of spots of known brightness, together with particulars of the plate for reference. The comparison spots are illuminated by light of the same type as that used in the street. The plate is carefully developed under standardised conditions, but development does not affect the results so long as it is even over the surface of the plate. Knowing the brightness of the spots photographed as a comparison, the brightness corresponding to each value of density in the plate can be found, and consequently the brightness corresponding to each part of the image can be determined. Fig. 13 shows a print from a typical plate. (Measurements are made, of course, on the actual plate, not on a print.)

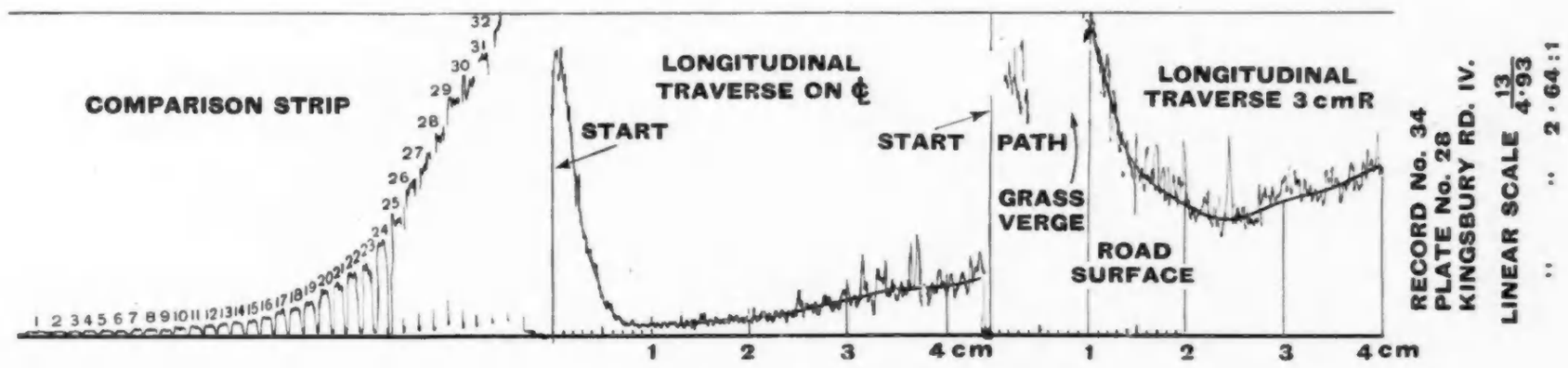


Fig. 14.—Typical microphotometer record.

It was fortunate that there was available a Moll recording microphotometer, used for the densitometry of spectrograms, which proved ideal for the determination of densities. In this instrument the plate is moved slowly in a carriage, and a very small beam of light passed through it. After passing through the plate the beam is focussed upon a thermopile, the output of which operates a galvanometer. This records its deflection upon bromide paper carried on a drum geared to the plate carriage. A typical record is shown in fig. 14, on which is the record of a comparison strip and of two traverses taken across the plate.

The deflection of the galvanometer is measured on the record for each spot of the comparison strip, and a calibration curve for the record is thereby obtained. The brightness corresponding to any point on the record is thus obtained directly from the calibration curve.

It will be seen that this method* avoids most of the troubles inherent in photographic photometry, in that the results are independent of the law of the plate, time and temperature of development, absolute values of density, or the calibration of the Moll microphotometer.

In addition, it has the following great practical advantages.

1. The field work can be accomplished comparatively quickly and in comfort, and all the tedious photometry is done automatically in the laboratory during the day. Furthermore, a complete record of the whole surface of the street is preserved, and further photometry can be done on the plates if required.

2. Difficulties of brightness measurements at low levels and at difficult colour differences are avoided. The only heterochromatic photometric balance which has to be made is that involved in setting the brightness of the comparison spots, which requires one determination at about 3 foot-candles level.

The photographic method, in effect, increases the brightness to be measured, and enables quite low brightnesses to be measured at a conveniently high level. Illumination readings must, however, be made in the street.

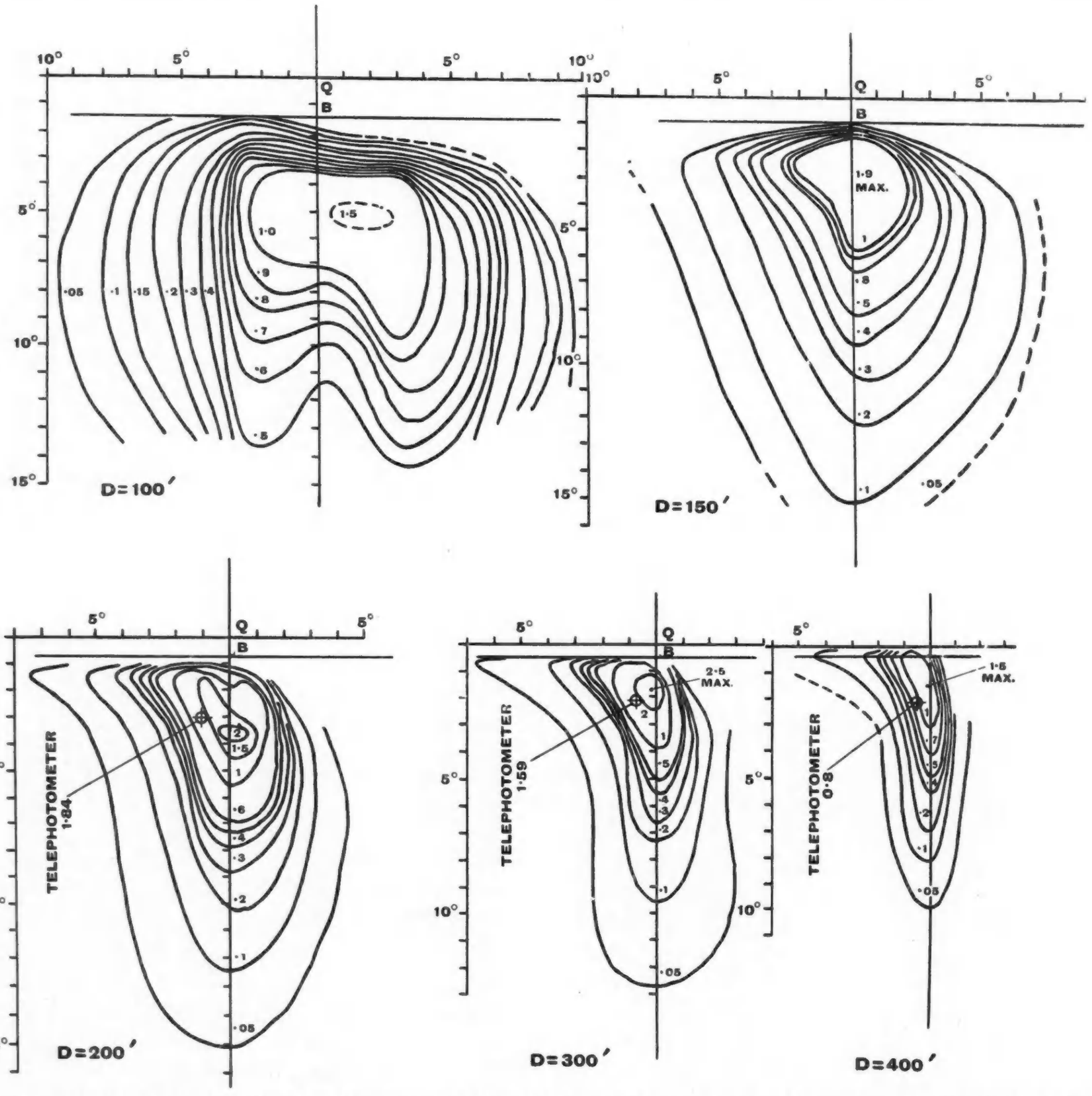


Fig. 15.—Brightness distribution for observer at different distances from source. Values in equivalent foot-candles.

* The method was obtained from "Photographic Photometry" (Dobson, Griffiths, and Richardson, Oxford, 1926), together with many practical details.

3. The actual appearance of the road surface is very mottled, as can be seen from the photograph, owing to slight irregularities. This makes photometry with a telephotometer a matter of some difficulty, for it is not easy to obtain a mean reading, although an improvement results if the telescope is used slightly out of focus. The Moll record, however, shows exactly the nature of the irregularities, and enables a mean line to be drawn through the oscillations which appear on the record. This enables the results to be faired at an early stage, and helps to avoid inconsistencies.

The plate must be evenly developed; this was accomplished either by swabbing during the whole period of development, or by the use of a special tank, as described in the reference quoted above.

Tests showed the method to be in good agreement with results obtained with an illuminometer. When the photograph is taken on the road, certain reference marks are left to appear in the photograph, at which also illumination measurements are made, and an electric torch is placed on the surface of the road, under the fitting, in order to provide a zero mark.

(*iii*) *Illumination Measurements.*

Illumination measurements are made with a precision illuminometer, on a test plate arranged normal to the incident light, at a sufficient number of positions to enable illuminations to be calculated for the remainder of the required positions. This avoids measurements of very low values, and errors due to the test plate.

(5) RESULTS.

At present, results have only been obtained for one surface, which was chosen as typical of a surface having useful reflection properties. Experience had shown that the reflection from this surface was sufficiently "spread" to produce wide streaks, and thus to enable a satisfactorily even distribution of brightness to be obtained. It was laid in accordance with B.S.S. 342, 1928. The wearing surface is composed of small gauge granite mixed with sand and bitumen, laid at the proper temperature, and consolidated by rolling. Before the mixture is too cold, pre-coated granite chippings are distributed over the surface. These chippings are of $\frac{3}{4}$" gauge Cornish granite coated with a very minute layer of bitumen. This surface is widely used at the present time, and, it is understood, its use is likely to be continued. The surface tested had had about eighteen months' wear.*

It will be realised at the outset that a great deal of variation occurs between one surface and another and even between different parts of the same surface, which have been differently worn. Precise and repeatable data are hardly, therefore, to be expected. All that can be hoped for is eventually to provide data for two or three characteristic road surfaces (*e.g.*, of high polish, good "spread" reflection, and approximating to matt), and in practical application to use whichever data are the nearest to the particular surface concerned. The surface tested comes in the second class. In the experiments readings were obtained from a single unit, consisting of a 400-watt high-pressure mercury electric discharge lamp, in a lantern mounted over the kerb at 25 ft. height, having an asymmetric distribution.

It is convenient to express brightness in equivalent foot-candles (abbr. e.f.c.), the unit being the brightness of a perfectly diffuse reflecting surface having a total reflection factor of 100 per cent and receiving an illumination of 1 foot-candle. The reflecting power of the surface will be expressed as a specific reflectivity—*i.e.*, the ratio of the brightness of the actual surface to that of a perfectly diffusing surface of 100 per cent reflection factor. A special assumption is made, however, which will be explained later.

The actual brightness distributions of the road surface from one unit are shown in fig. 15, for the five different distances indicated.* The investigation was made on the right-hand side of the road, and the road surface near the kerb was not worn and polished to the same extent as the surface further out; but the camera positions were chosen so that the streak was formed as far as possible on a uniformly polished part of the surface. A few check readings were made by telephotometer and are marked in the figure: it will be seen that they are in good agreement with the results obtained from photographs.

This series of results provides some interesting observations.

(a) Shape of Patch.

At 100 or 150 feet from the unit the patch is ill-defined and of large extent. As the distance increases, however, it begins to lengthen in the direction of the observer and to take up a characteristic ⅂ shape.

(b) Brightness.

The maximum brightness does not vary very greatly; the highest value of 2.5 e.f.c. occurs at 300 feet, and the lowest of 1.5 e.f.c. at 100 feet and 400 feet. The brightness beyond the bright patch is of the order of 0.05 e.f.c. The values of maximum brightness are liable to considerable variation as a result of differences in degree of polish, and are not important. The minimum brightness is much more important, as determining the brightness of the dark parts of the road surface.

(c) Position of Maximum Brightness.

A very curious phenomenon may be observed in

* For the above information the author is indebted to Major W. H. Morgan, County Surveyor of Middlesex.

* It is hoped shortly to extend the investigation to 600 ft., but results are not available at the time of writing.

the position of the region of maximum brightness. It would naturally be supposed that the maximum brightness would occur at one of two positions—either where the illumination on the road is greatest, or centred about the region at which, if the surface were a mirror, an image of the light source would be formed. Actually the maximum brightness is at neither of these places, but the bright region begins at about 30 feet from the post in every case, and the maximum occurs there or a little beyond. The image point is found, curiously enough, to come near the end of the streak.† This latter conclusion is confirmed by observation of a large number of photographs and of actual installations. On a dry road, except when the surface is unusually highly polished, the streak extends only a little way beyond the image point, and it is generally unwise to rely on a streak of much greater length. It is easy to show‡

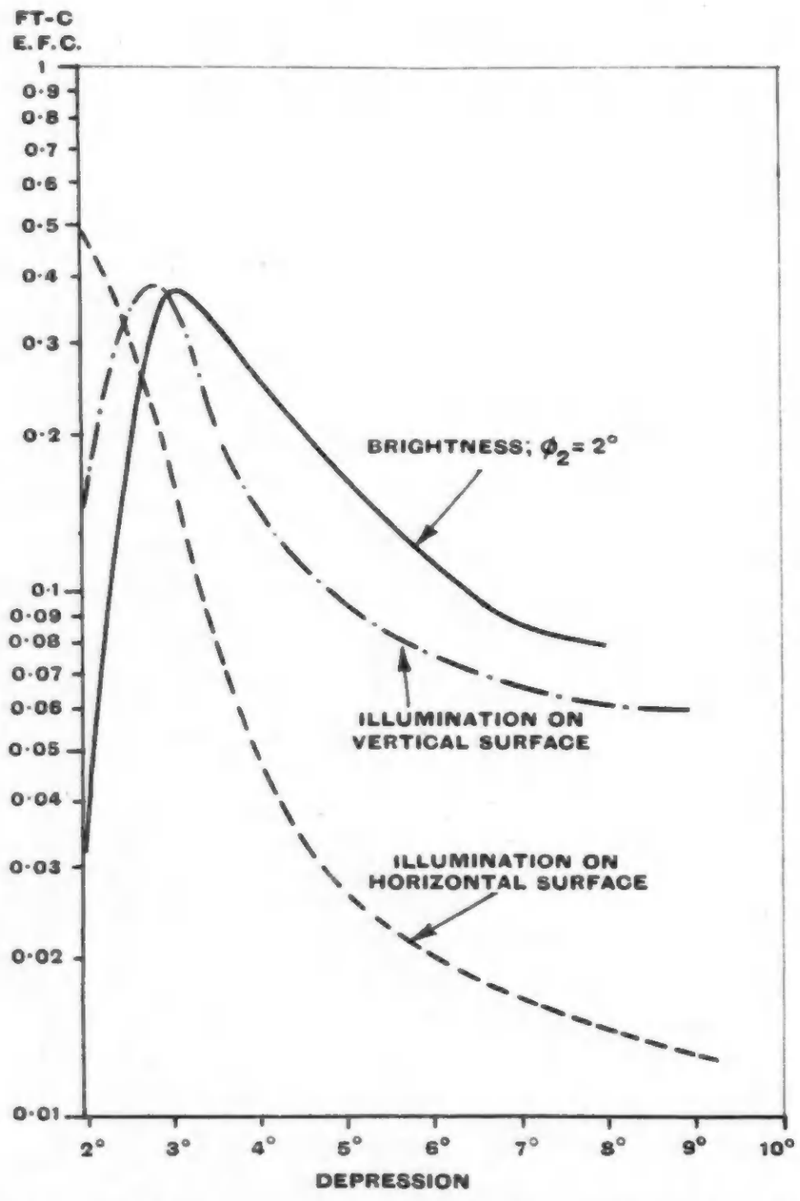


Fig. 16.—Brightness and illumination along length of streak; not on centreline.

that the distance of the image point from the source is D.H/ (H + *h*), or from the observer, D.*h*/ (H + *h*). When the road is really wet, however, the image point may become the brightest point in the streak, which is then very narrow. The position of the maximum brightness is curious, and no physical explanation has so far suggested itself. The curves of brightness measured along the streak do not show the slightest resemblance to the curves of illumination on the surface (fig. 16). In fact, in calculating reflectivities, it becomes evident that the values obtained at large distances from the unit become very great—reflectivities are found of over 500 on this basis, even for the not particularly polished road investigated—simply because at these distances the

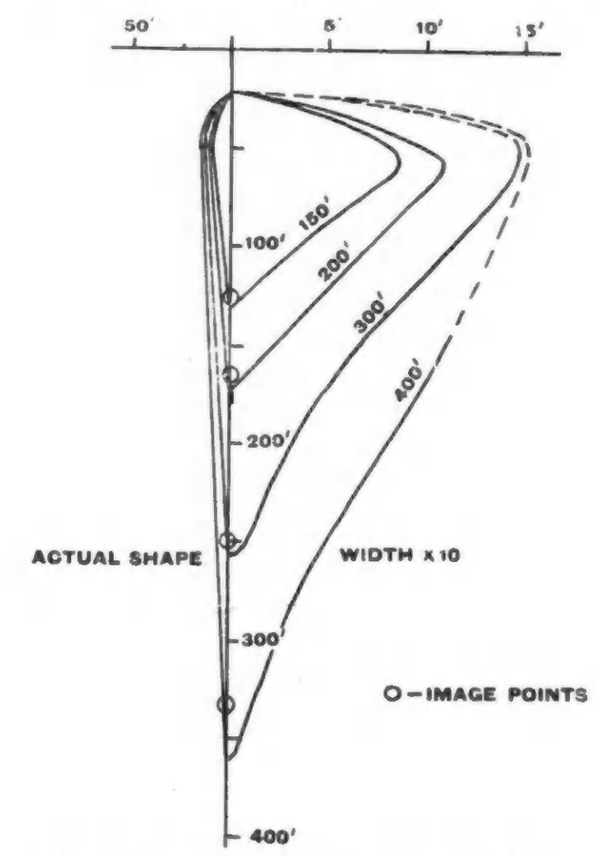


Fig. 17.—Plan of bright patch on road surface when viewed from different distances.

illumination is very low. At about 350 feet from the unit the surface brightness in the centre of the streak is well maintained, whereas the horizontal illumination has fallen as low as 0.0005 foot-candle.

In the first test made it was observed, however, that the brightness followed much more closely the curve of illumination on a vertical surface than on a horizontal, as can be seen in fig. 16. The position of maximum brightness is in this test very closely the position of maximum vertical illumination in each case. This is not illumination on a vertical surface as generally understood, for it is the illumination on a small vertical face on the road surface, on the side remote from the observer, which he would not be able to see. This follows the brightness much more closely than does the more conventional horizontal illumination, and has been taken as the basis of the reflectivities given below. The reason for this correspondence is not clear. There is not necessarily any real physical significance in the illumination on a vertical face. It also remains to be seen whether other surfaces show the same characteristic, which may turn out to be entirely fortuitous.

(d) Brightness of Road Surface Beyond Source.

All the evidence, both from the tests made and from observation, goes to show that except on matt roads the brightness of the road surface beyond the post generally is negligibly small and cannot be relied upon as a background.

† Later work shows that when the surface becomes more polished the brightness maximum is closer to the observer and the value of brightness is higher. The maximum does not occur at the image point, however, unless the road surface is very highly polished or very wet.

‡ Waldram, A.P.L.E., 1928.

(e) Limit of Bright Streak.

From observations on the street and on the photographs and comparison with the contours, it appears that the extreme effective edge of the bright patch can be taken as 0.2 e.f.c. for the road explored, or about $\frac{1}{10}$ maximum brightness. Actually the streak has no sharply defined edge, the brightness diminishing continuously to a minimum of about 0.05 e.f.c. The rate of fall varies with the degree of polish; with the more matt surfaces it is not easy to say where the limit of the streak is reached. With more polished surfaces it is more clearly defined. The bright is of the shape shown in fig. 17. It is about 15 feet wide at about 50 feet from the post, and it tapers to nothing at about the image point or a little beyond. It does not appear to vary very much in actual width as the observer's distance from the source varies.

(g) Values of Reflectivity.

The reflectivity of the surface, calculated as the ratio of its brightness to the illumination on a small vertical face at the point concerned, has been plotted in fig. 18 in contour form to correspond with

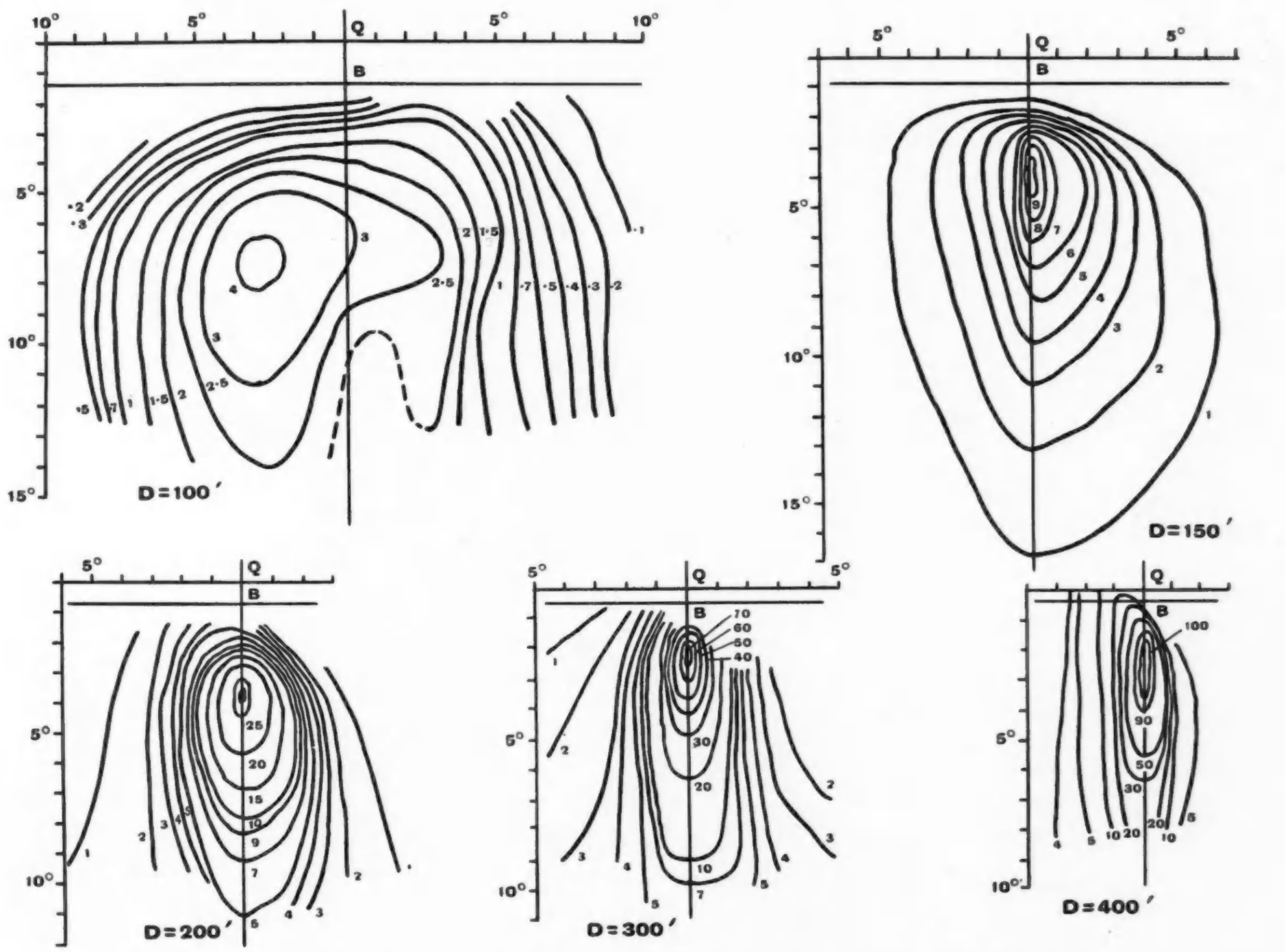


Fig. 18.—Contours showing values of reflectivity for an observer at different distances from source, on basis of illumination on vertical surface.

region between streaks, however, is not of zero brightness, and its brightness may be enhanced by suitable distribution of light. The value of 0.2 e.f.c. is chosen arbitrarily and extends probably beyond the obvious limit of the streak, but corresponds to the region over which the brightness is sufficient effectively to reveal objects.

(f) Size of Actual Patch on Road.

If the 0.2 e.f.c. contour is replotted on to the plan of the road surface, it is found that in the installation measured, the patch of road which is effectively

fig. 15, and in figs. 19-23 in the form of diagrams to be laid over fig. 11, for values of δ of 0°, 1°, 2°, 3°, and 4°, and, in Table 2, for the plotting of the head of the "Tee" of the streak, for three special values of δ of 15°, 30°, and 45°, when $i = 45°$, as explained below.

From these sheets the brightness distribution at any distance from a source having any light distribution, and at any given height, can be computed. The procedure is as follows:—

The skeleton perspective web with scales of r, ϕ_2 and δ for the appropriate distance, is first

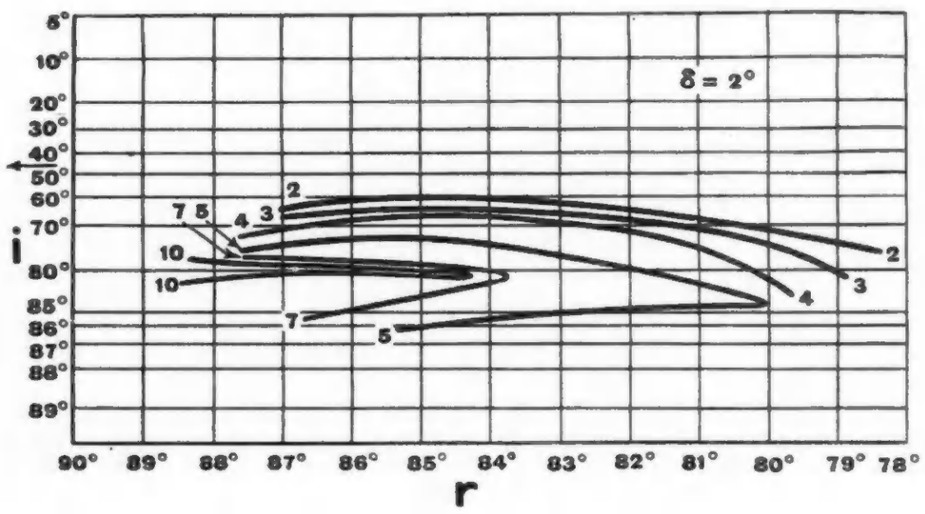
drawn (as in fig. 10). One of the data sheets, figs. 19-23, is then laid over fig 11, with its index arrow opposite to the appropriate mounting height, and the reflectivity for each value of r is found by the intersection of the appropriate D curve with the contours on the sheet.* These values are tabulated or marked on the perspective web along the δ line corresponding to the sheet used. From the polar distribution of the fitting, the illumination on a vertical surface at the corresponding points is found, and similarly tabulated. The transformation from θ, the angle on the polar curve, to r, the angle in the perspective, is performed with the aid of fig. 11. Except for points of view very close to the source, the effect of change ϕ can generally be neglected—*i.e.*, the illumination along any line drawn across the streak is assumed constant. By multiplying the illumination by the reflectivity, the brightness is obtained of each point, and if this process is repeated for the various values of δ and plotted on either side of the centre line on the perspective web, the distribution of brightness in the streak is built up.

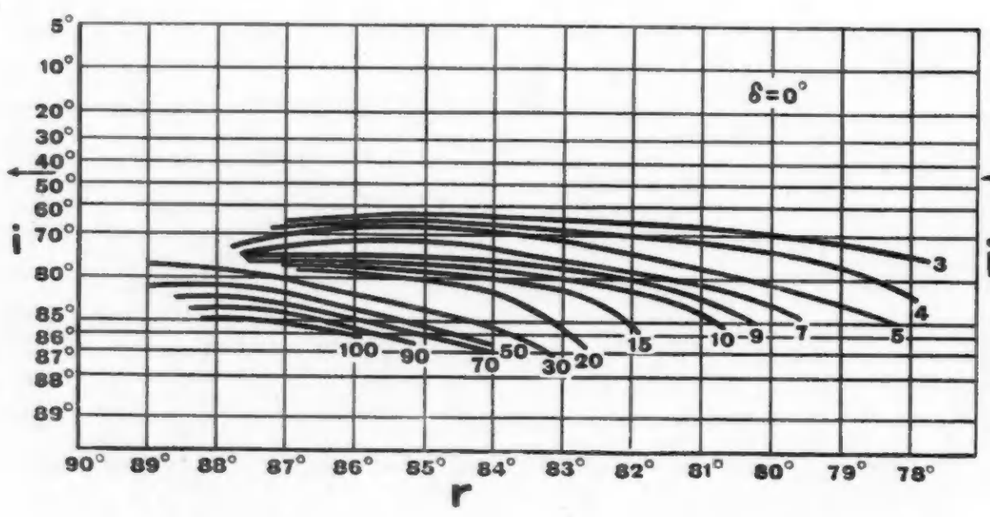
This method is not convenient for the head of the "Tee," because in this region the δ lines are too cramped. The following artifice is therefore employed.

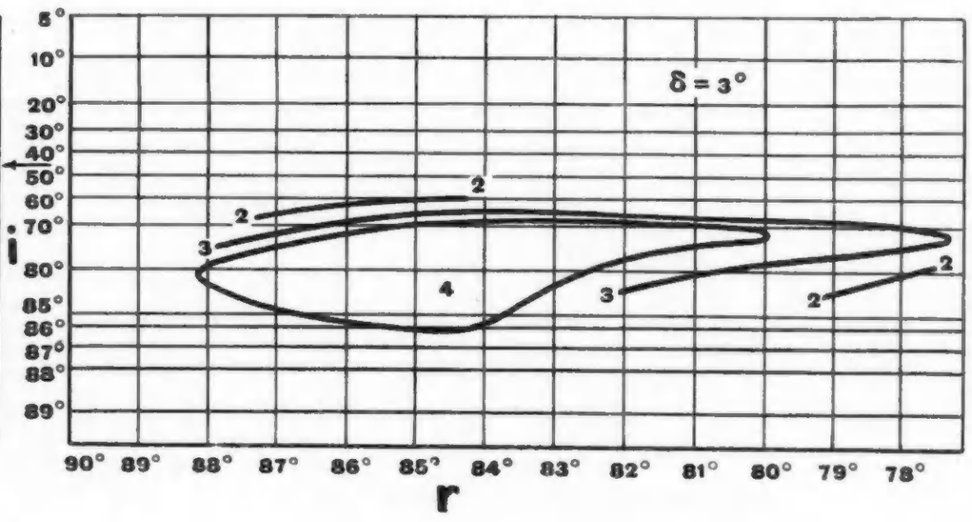
The head of the "Tee" of the streak is taken as being formed by light incident at approximately 45°, and its centre line will, therefore, be a line across the road at a distance H from the light source. This can be drawn with the help of fig. 7.†

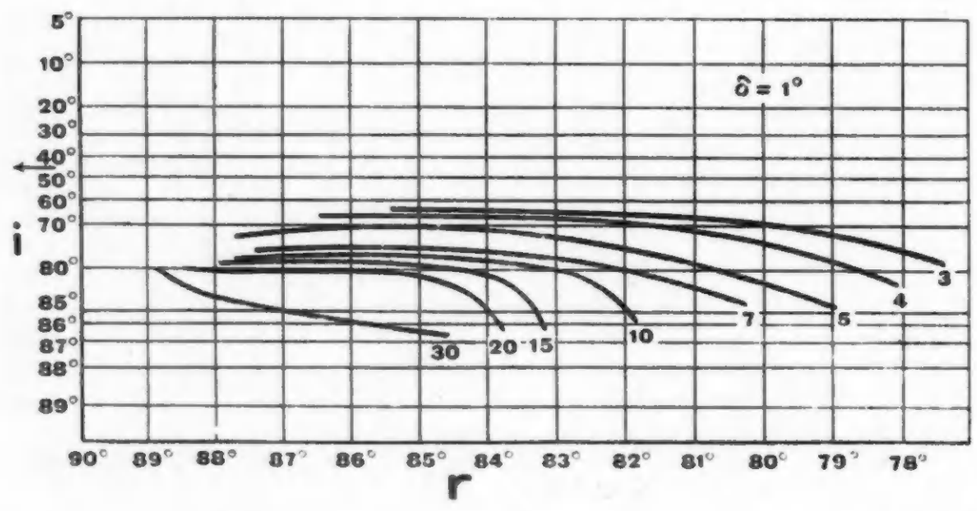
On this line three points are marked on each side of the centre line, at distances from the centre line of 0.255 H, 0.533 H, and 0.89 H. At these points, δ will be approximately 15°, 30°, and 45°, and the value of ρ is given above.

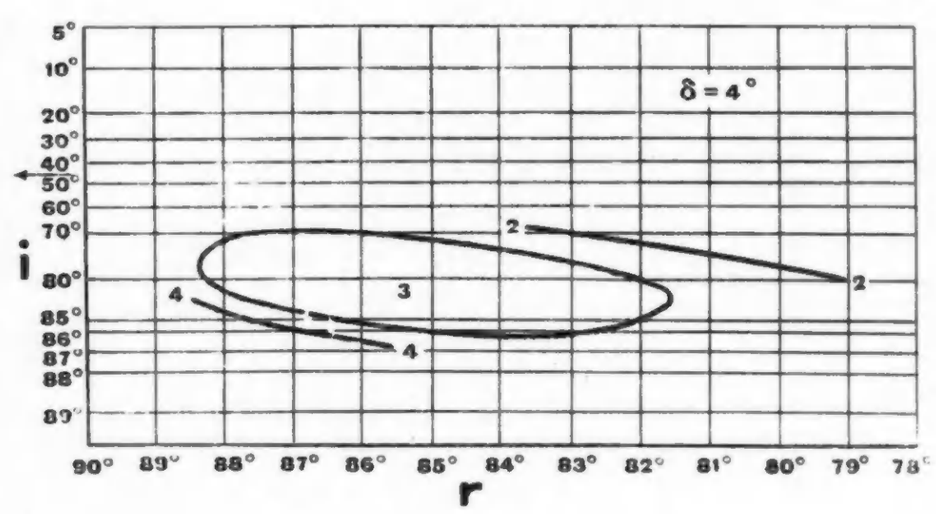
These values are approximately correct for all distances between 200 and 600 feet inclusive, and all mounting heights between, say, 13 and 25 feet. If the illumination at the same points on a vertical surface facing the light source is calculated, the brightness can be found and the distribution across the head of the "Tee" of the streak will be obtained.











Figs. 19 to 23.

* The data given in figs. 19-23 is not quite complete and is not sufficient to cover all cases.

† Or from the formula:

$$t = \frac{PQ}{D(D-H)} \qquad \ldots\ldots(2)$$

where t is the distance on the perspective of the head of the "Tee" below the foot of the post, and PQ is the perspective distance.

The corresponding values of θ and ϕ_1 are given in Table 2, in order to define the angles at which intensities are read from the distribution curves of the fitting.

TABLE 2.

Data for calculating head of "Tee."

Position.	δ	θ	Φ_1	ρ
0	0	45°	0	2.9
.255H	15°	46°	14¼°	2.2
.533H	30°	48½°	28°	0.5,
.89H	45°	53½°	41½°	0.2,

(6) EFFECTS UPON DESIGN.

Considerations of surface reflection characteristics affect differently three individuals who contribute to the final installation : the designer of the installation ; the designer of the equipment; and the road engineer, who provides the surface. They will be considered in that order.

The designer of the installation will not wish to be involved in all the intricacy of calculations of shape and size of patches, but will desire simple rules for determining the height and location of his sources, and some guidance as to the type of equipment to select. The fittings designer will be concerned in the optimum polar distribution to produce the largest and most uniform patch with a good road surface, so that in the complete installation as large an area of the road surface as possible is effectively bright ; the road engineer will wish to know what characteristics are the most helpful to the street lighting engineer and the motorist.

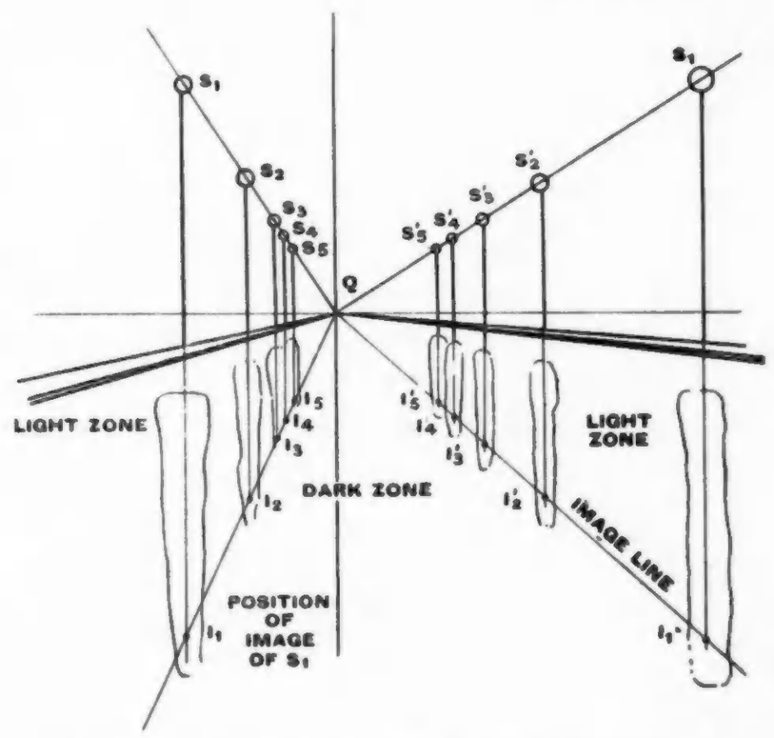


Fig. 24.—Road with double side mounting.

(a) Height of Posts.

One of the peculiar results which has been noted above (paragraph 5 (c)) is that the image point lies close to the end of the streak. Since the brightness of the streak is high, visibility is excellent over such parts of the road as are covered by them. But in other parts the brightness is generally low, and visibility is liable to be poor except when the illumination is very high, or with certain types of road surface. When the mounting height is low, or the road unduly wide, there is liable to be formed a dark zone (in the middle of the road when sources are mounted on both sides) which may constitute a danger zone. Now the size and position of the dark zone can be correlated with the height of the posts and the width of the road, and it is possible to formulate a limiting condition, which may help to ensure proper visibility.

Fig. 25—Example of light and dark zones shown in Fig. 24.

The general appearance of a straight road is shown in fig. 24. The sources will lie on two lines passing through Q, which may be called the source line, and corresponding to each source line will be an image line QI_1, QI'_1, upon which the specular images would fall. The parts lying between the image lines and the feet of the corresponding posts are likely to be bright, whereas the remainder—in fig. 24, the triangular space between the image lines—is likely to be dark. This is seen in the photograph of fig. 25.

It follows that the position of the image line is important. The position of the image line will depend upon the height of the sources and the lateral

position of the observer on the road. As the mounting height increases, the source lines and image lines more nearly approach the vertical, and the triangular dark space decreases in extent.

Now this triangular space in the perspective view corresponds in plan to a parallel strip of road surface ; and it can easily be shown that, if the

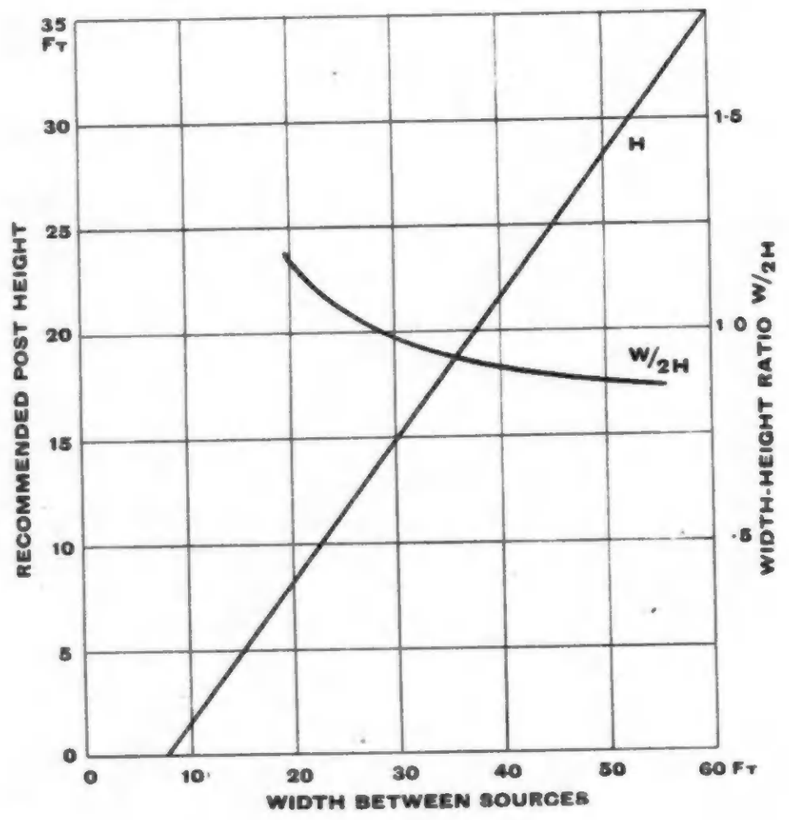


Fig. 26.

observer moves laterally in the street, the position of this strip changes, but its width remains unaltered.

It can also be shown that the fraction of the road width (measured between the sources) which is likely to be rendered effectively bright, will be equal to

$$H/(H+h) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This is an interesting result, for it appears that the proportion covered is independent of the width of the road. It is, therefore, an easy matter to find what height of post will produce, for any given width of

TABLE 3.

Mounting height necessary to give a maximum strip width of 7 feet 6 inches between image lines, for different widths between lines of sources.

Width between lines of sources.	Mounting Height.	Width-Height Ratio, W/2H.
20 feet	8.4 feet	1.2
25 „	11.7 „	1.07
30 „	15 „	1.00
35 „	18.4 „	0.95
40 „	21.6 „	0.93
45 „	25 „	0.90
50 „	28.4 „	0.88
55 „	31.8 „	0.86$_5$
60 „	35 „	0.86

road, a strip of given width between the image lines. The relation is

$$H=(W-W_0)\,h/W_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where W is the width of the road measured between sources and W_0 is the width of the strip between image lines.

Now it is evident from what has already been shown that the streaks have a considerable width ; in the case of the surface investigated, the width from the centre line varies from 0 to 15 or 20 feet, the latter width being at the part of the streak near the foot of the post. The important part in the perspec-

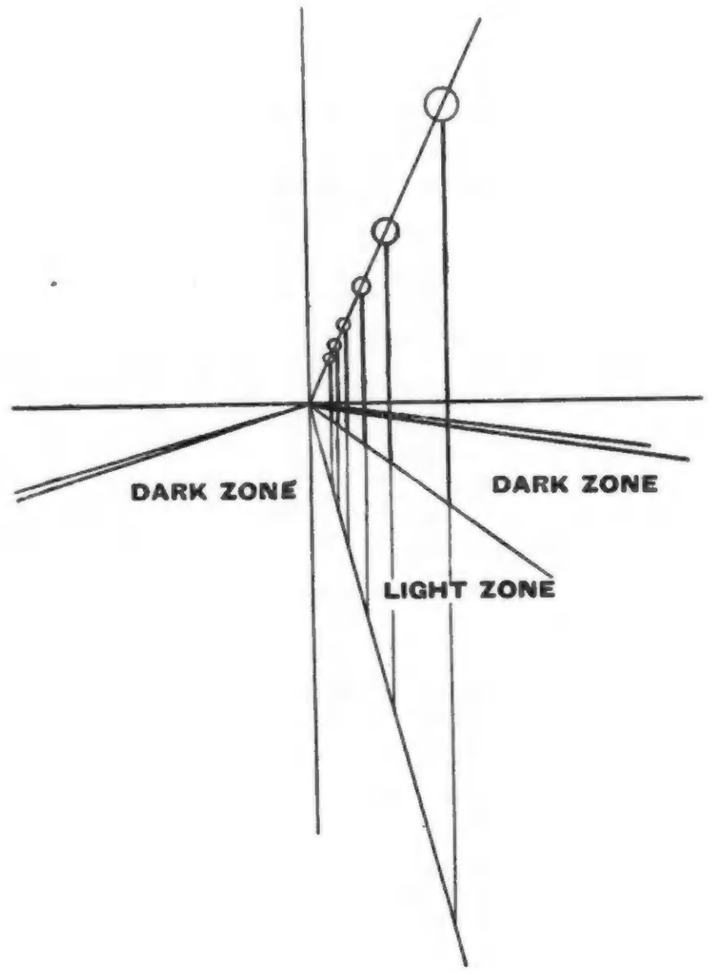


Fig. 27.—Roads with central and with single side mounting

tive view is probably about 3-4 feet in width. This implies that if the width of the strip between the image lines is about 7 feet 6 inches, the width of the streaks will be sufficient to fill up the strip and prevent the brightness there from becoming unduly low.

Taking W_0 as 7 feet 6 inches, therefore, the necessary height of source can be worked out, giving the results of Table 3, which are plotted in fig. 26. The Table gives also the value of the width-height ratio, W/2H.*

This, it will be seen, varies slowly with the width of the road, but for ordinary widths is in the neighbourhood of 1 or slightly less. This is in accord with practical results, for a careful study made of the installations shown in Sheffield at the 1928 Conference of the Association of Public Lighting Engineers had previously shown that a value of W/2H of 1, or thereabouts, is satisfactory from the point of view of avoidance of dark strips on the surface.

The above results apply to sources on both sides of the road. Where the sources overhang the carriageway materially there will tend to be a dark space between the line of sources (in plan) and the kerb, although the fact that this part of the road is little worn and is generally matt may increase the brightness sufficiently.

Where the sources are in the centre or on one side only, however, the above results require modification. In the first place, on a polished road surface the centrally suspended system can never render effectively bright the further half of the road; the streaks lie always in the half nearer to the observer. (See fig. 27.) Consequently, the proportion of the road covered is always less than half, and depends upon the position of the observer in the road. The road to the left of the observer is always dark (unless the road curves to the left), which constitutes a real danger, for this is precisely the region in which cyclists and slow-moving objects are found. The proportion H/ (H + *h*) given above applies only to the part between the observer and the line of sources.

The same remarks apply to single side lighting, when the above proportion applies to that part of the road between the observer and the line of sources, and therefore varies according as the sources are on the left-hand or the right-hand side. Both these systems are, therefore, at a disadvantage as compared with the systems with sources on both sides of the road; the single side system is particularly so. This latter system is often really dangerous, and it is particularly to be hoped that it will not be used in new installations except where circumstances make it unavoidable. In the author's view, single side mounting is worse than nothing at all, for it leads the driver to think that he can see without headlights when in fact he cannot.

* The width-height ratio has been taken as the ratio to the mounting height of that width of carriageway which can be considered as lighted by one line of sources. For sources mounted on both sides or in the centre, this width will be one-half the width between the lines of sources; while for sources mounted on one side only it will be equal to the width of the carriageway. The corresponding width-height ratios are $\frac{W}{2H}$ and $\frac{W}{H}$

(b) Position of Sources.

Having decided upon the height, the designer of an installation will wish to know, most of all, how he can locate his light sources to the best advantage. He will not generally be interested to undertake the labour of calculating the size of the patch produced for he will have to make use of standard units and light sources. It may be hoped that before long the designer of equipment will work out by the methods given and supply once for all for this or some standard type of road surface, the size of patch on the road which any particular equipment renders effectively bright. Work on this subject is not complete, but it seems likely that the maximum width of patch will vary slowly with change in the height of the post. The designer of the installation can do a great deal, however, if he only guesses at the size of the patch from experience, and then plots it in perspective by the simple method shown. It will, of course, be recognised that the edge of the patch is not a sharply defined line, but the brightness actually diminishes continuously from the centre line. For convenience, however, since the falling off of brightness is rapid, a given brightness can be taken and

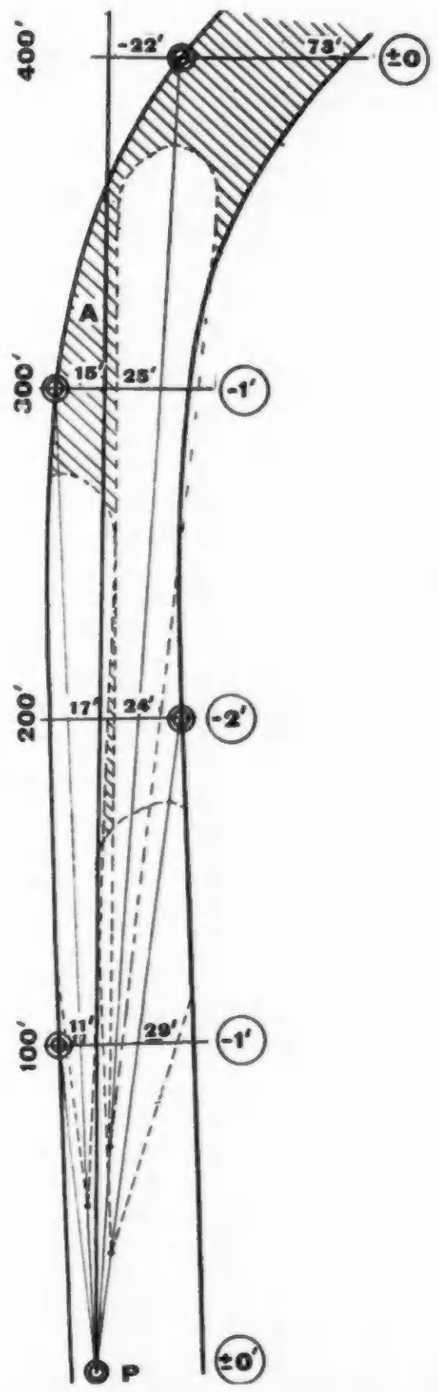


Fig. 28.—Plan of roadway showing bright streaks. (Figures in circles represent height of road surface in feet above (+) or below (—) level at P.).

designated the limit of the patch. A value of about 1-10th the maximum brightness is probably a suitable value.

Suppose, for example, that the height of the post and the lighting fitting are the same as those on which the photometry was done and to which fig. 15 refers. The size of the streak is then about 15 feet maximum width, tapering uniformly to the image point or thereabouts: the axis of the streak lies always on a line through the observer. If the trial positions of the units are decided, the patches can be set out in plan quite easily, and by inspection of the plan and trial and error, the best positions for the units can be settled approximately. At the same

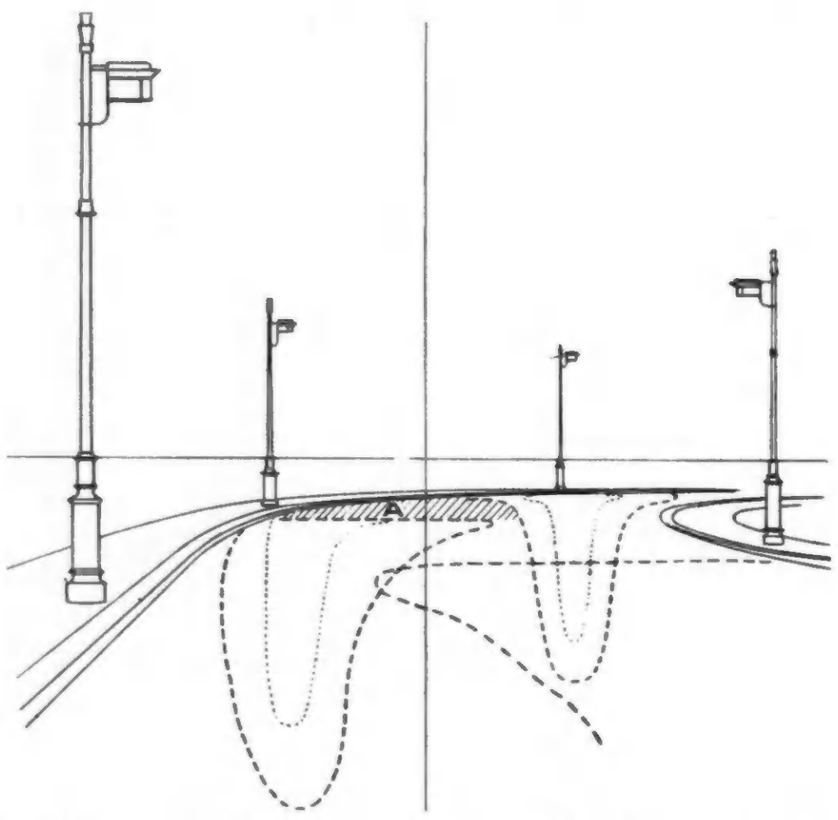


Fig. 29.—Perspective view of road of Fig. 28, seen from P.

time a critical view-point can be found, at which visibility is likely to be bad, and for this point a perspective can be drawn, including the perspective of the streaks taken from the plan, as in fig. 29. In this way the appearance of the street can be forecast fairly accurately. In fig. 28 the patches have been considered as triangular in shape, which is sufficiently accurate for the purpose of a plan. When drawing the perspective it is necessary to take the shape of the patch more exactly, for the sides are really concave. In fig. 29 the edge of the patches shown is the 0.2 e.f.c. contour. This is probably wider than the apparent width, as already stated: the bright appearance on the road would be more like the fine dotted lines shown.

It is important to consider what happens as the motorist proceeds along the road. It may be that at one position in the road a certain region about 300 feet ahead is left without bright background, and is therefore dangerous. As the motorist proceeds the positions of the streaks will generally move, and it may be that as he approaches the dangerous region a bright streak will cross it and reveal any obstruction in good time. It is suggested that any region which may be left without bright background until the driver is within 150 feet of it is really dangerous and steps should be taken, by altering post positions if possible, to avoid the danger. The designer must, of course, consider traffic in each direction.

In the example given in figs. 28 and 29, two faults are revealed. It will be seen that the designer has wisely departed from the diagonal system in order to have the post at 400 feet on the outside of the curve, but has retained the spacing at about 100 feet. In doing so the last post is so far to the right from the point of view of a driver at P, that a region of the road marked A in both views is left dark; and if the position of the patches is studied as the driver proceeds up the road, it will be found that most of this region will continue to remain dark until the car reaches it. The region A is therefore dangerous. The perspective reveals another more subtle mistake which may easily be made. The same post having been placed on the left-hand kerb is out of order in the diagonal installation. As it is seen from P it looks—owing to the bend—exactly as though it were on the right-hand side of a straight road, and since the kerb between the third and fourth sources is likely to be dark, there is danger of a motorist failing to realise that the road curves, particularly if the view of the other posts is otherwise obstructed, or in fog, and driving into the kerb.

(c) Influence on Fittings Design.

The fittings designer wishes to have a definite basis upon which to design his distribution. Up to the present, distributions have been settled empirically, frequently by the costly process of producing a new refractor or reflector and trying it out. It has not been possible to lay down an optimum distribution upon any definite basis connected directly with road reflection properties, although certain guiding principles for the production of a smooth brightness distribution have been known.*

It is hoped that, as a result of this work, such a basis may be evolved. This has not yet been completed, but some of the desirable features of distribution may be noted.

(i) For the provision of long, useful streaks, the intensity should not be cut off above the "peak" angle of 70°-80° from the vertical, but a reasonable intensity should be provided up to 89° or 90° from the vertical. It may be necessary to reduce intensity somewhat at this region, on account of glare, but the amount of reduction has not yet been decided. It is certain that with a suitable road surface quite high values of intensity can be tolerated before the glare effects begin to outweigh the advantages of the large areas of high road brightness.

(ii) It is evident that when the road surface is at all polished, the system in which light is directed

* Wilson, Illn. Engineer (London), 1933, p. 151.
Waldram: Roy. Soc. Arts J., Feb., 1934, p. 303.

only in the direction of the traffic is at a great disadvantage, for the reflectivity of the road beyond the post (when *i* is negative) is very low indeed, and enormous intensities would be necessary to provide anything like the same brightness as can be produced with the direction of the light reversed. The bi-asymmetric distribution, however, in which a good intensity and a wide distribution is provided against the direction of the traffic (so as to produce good wide streaks and a satisfactory brightness), and a greater intensity and narrower distribution in the direction of the traffic, has an advantage. It provides for the motorist with the wide beam, while the narrower beam illuminates the kerb and its vicinity, and is of great help to the pedestrian and cyclist, who depend less upon distant bright streaks. At the same time, the narrow beam of high intensity avoids excessive glare, since the motorist is not in this beam.

(iii) The width of the streak is determined largely by the road surface reflection properties, but the greater the intensity at regions above the peak angle, the greater will be the width of the streak. Asymmetric distributions should therefore be wide enough to provide a good intensity in all horizontal directions from which the motorist will normally be viewing the road surface. A wide "peak" to the distribution is of the greatest value, because it raises the brightness of the dark zone between streaks, particularly on the more matt surfaces. It is the dark spaces between streaks which are the danger zones, and which must be studied in order to ensure "accident proof" lighting.

(iv) It has been found by experience that a "flat bottom" polar curve, as shown in fig. 30, curve b, has an advantage over the older "waisted" distribution (curve a), for the older type produced a peculiar shadow across the road surface which was unpleasing. Investigations using the results obtained for reflectivity have confirmed this. The ideal curve for uniform brightness is practically "flat bottomed" from 45° upwards. Below 45°, the brightness is bound to fall off, for reasons which will be obvious from the results obtained; for the reflectivity near the post is very low, and for uniform brightness within 25 feet of the post, enormous intensities would be required. If the brightness due to the old waisted distribution is calculated, the shadow can be found either as an arrest in the curve or as a definite decrease in brightness.

The familiar polar distribution in a vertical plane can be analysed as in fig. 31, so as to demonstrate the different functions which different parts of the distribution fulfil. In the diagram the three annular zones show: (1) the regions of the curve useful to the different users of the street; (2) the contribution made by different regions of the curve to the appearance of the road and the brightness of the surface; and (3) the functions of the various parts in producing illumination on the road surface. This diagram relates to traffic in one direction only. From the point of view of appearance and visibility, only that portion from 45°, which forms the useful broad head of the "T" of the streak, up to 90°, which forms the distant streaks which help the driver, is of real value.

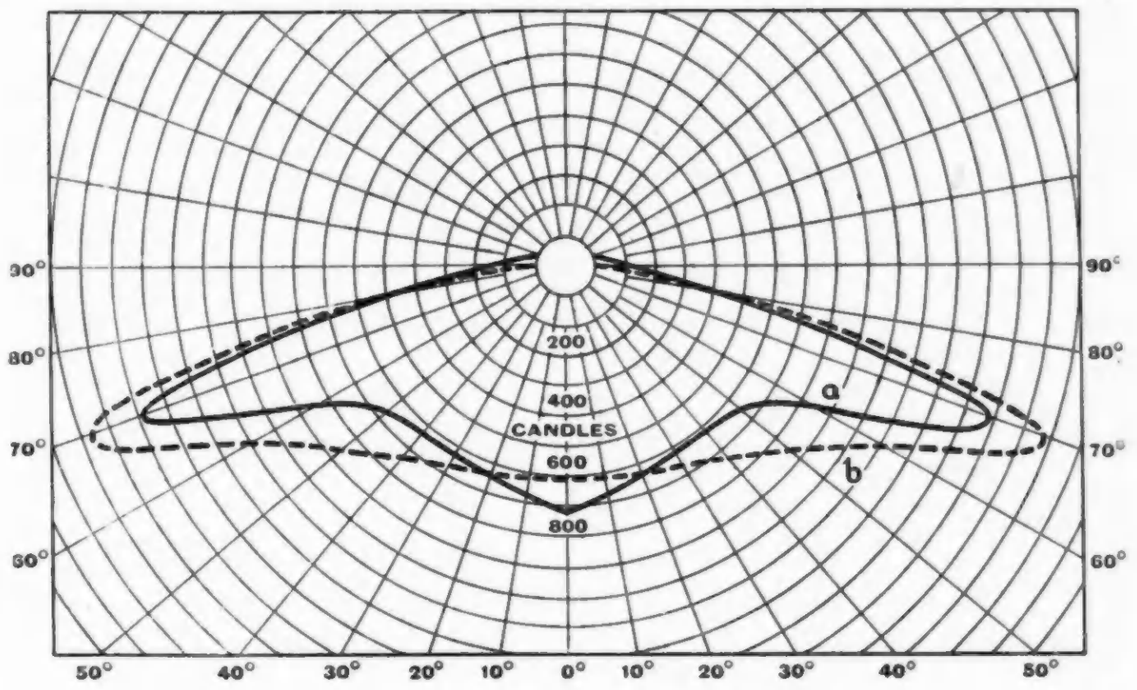


Fig. 30.—Polar curves of light distribution in vertical plane from old and new refractors.

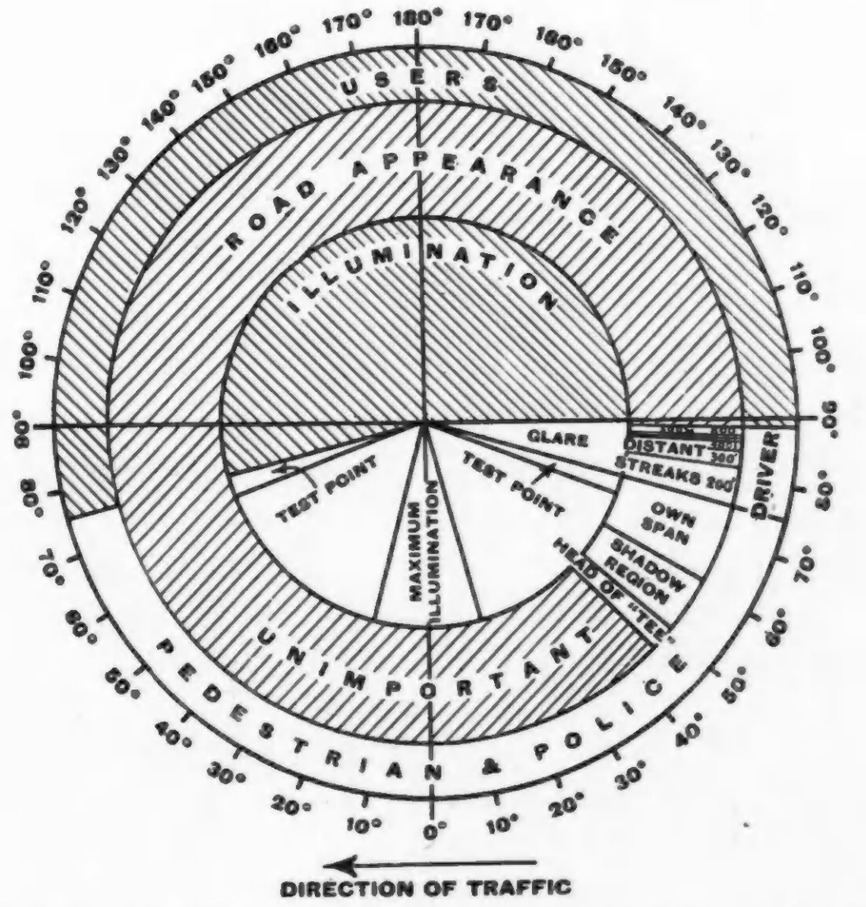


Fig. 31.—Analysis of the functions of light distribution in vertical plane.

It is particularly to be hoped that as knowledge of road surface characteristics increases, manufacturers may be able to supply, in addition to, or instead of, polar curves or iso-candle diagrams, data of the size

and/or brightness distribution of the streak or bright patch formed on some standard surface of known reflection characteristics. This will be a real indication of the usefulness of the unit, and might lead us eventually to some real figure of merit either for the lighting equipment or for the complete installation.

(d) Desirable Types of Road Surface.

Work has not yet progressed far enough to decide precisely what characteristics are desirable in a road surface, or how they may be obtained. It is evident from observation, however, that certain surfaces are much more helpful to the street-lighting engineer than others. It may be observed that the characteristics which favour the street-lighting engineer are precisely the reverse of those which help the motorist who relies upon headlights. The former requires a surface having a "spread" reflection characteristic in which light is reflected mostly on the side of the normal away from the light source; the motorist requires a surface which will reflect back on the side of the normal towards the light source. A road which has been tarred and sanded with light-coloured sand or gravel, or a water-bound macadam road, or a country road with a chalky surface, is excellent for the motorist. The modern large-aggregate asphalt roads with a slightly polished surface are excellent for the street-lighting engineer. If such a surface is tarred and sanded, the visibility and good appearance in such a road may be ruined, and the glare from the lighting units apparently increased.

There are some asphalt surfaces which present a uniformly smooth surface and which, with wear, become very highly polished indeed and slippery. This degree of polish is unduly high and approximates to a wet road. The same surface when wet "floods" very rapidly and apparently remains covered with a film of water for some time after the rain has ceased. The larger aggregate surfaces, such as the one tested, seem to dry off rapidly and do not flood so readily—possibly owing to the presence of innumerable small indentations and channels in the surface, which seem to result from the final application of chippings. This type of surface is preferable for the effective visibility from street-lighting. It is probable that concrete surfaces have an advantage from their light colour, but to what extent is not yet known. In addition, they appear to possess, when worn, desirable reflection characteristics similar to those of the surface tested.

(7) CONCLUSION.

This article is a record of progress rather than of a finished piece of work. Experiments are continuing at the time of writing, and further conclusions may have been reached before the paper is presented. Already new methods of test have suggested themselves. It is hoped that such guidance as it has been possible to obtain from the results up to the present may be of use to those engaged in the practice of street-lighting, and that the discussion will provide guidance for those engaged in laboratory work. Let us hope that we may soon reach the position of being able to measure and express in figures what we have discussed at so many Conferences, and may be able at last to plan streets as we see them. Then, according to Lord Kelvin, street-lighting may call itself a science.

"Osira" Street Lighting.

Chepstow Road, Newport, Monmouthshire, illuminated by 400 watt "Osira" lamps housed in Lewisham type lanterns. This installation was carried out as a result of special tests in which "Osira" lamps were found to give the greatest road brightness. The work was supervised throughout by Mr. A. Nichols Moore, M.I.E.E., Borough Electrical and Tramways Engineer.

Train Describers

WITH SPECIAL REFERENCE TO NEW MAIN LINE EQUIPMENT INSTALLED BY THE LONDON & NORTH EASTERN RAILWAY.

By F. L. CASTLE, A.M.I.E.E.,
General Manager of Siemens and General Electric Railway Signal Co. Ltd.,
and
B. F. MOSS, G.E.C. Telephone Works.

Fig. 1 (above).—A train passing through the new station at Shenfield on the L. & N.E. main line from London to the Eastern Counties. Between Shenfield and Romford a comprehensive train describing equipment has been installed.

Fig. 2 (left).—A typical section of the line at Gidea Park.

THE phrase "Train Description" is a technical term used by railway signalling engineers to denote some form of illuminated display system, by means of which signalmen and passengers are informed visually not only of the "description" of approaching trains, but also the order in which they will arrive.

For signalmen, this display in its simplest form consists of a cabinet, or cabinets, installed in the signal box. On the front of the cabinet are mounted a number of labels engraved with various descriptions of trains such as "Fast Electric," "Steam Passenger," "Main Goods" and the like. Beside each label is a lamp, or series of lamps, the lighting of which provides an indication to the signalman that a particular type of train has entered the section of the line under his control. In some instances, numbers are used in place of names: the signalman then identifies the type of train indicated by the aid of information already in his possession.

For passengers, the information received by the signalman can be repeated by illuminated signs on the station platforms to show the ultimate destination of the train, or it can automatically be decoded to display the names of all the stations at which the train will stop.

It will be appreciated that to cope with modern railway traffic conditions, signalling practice during recent years has been advanced in its application to allow several trains to be on one section of line between successive signal cabins. In such areas, it is highly desirable that the signal cabins are provided with a comprehensive form of train describing apparatus so that the signalman may know at any instant, by observing his describing receiver, the descriptions of all the trains in his section. It is proposed in this article first, to outline the fundamental principles involved in train describing and, secondly, by way of illustration, to describe the equipment recently installed on the London & North Eastern Railway.

OPERATING PRINCIPLES.

The particular system of train describing under discussion depends for its operation upon a number of electrical impulses being transmitted and received over two line wires, the number of impulses being varied for individual descriptions transmitted.

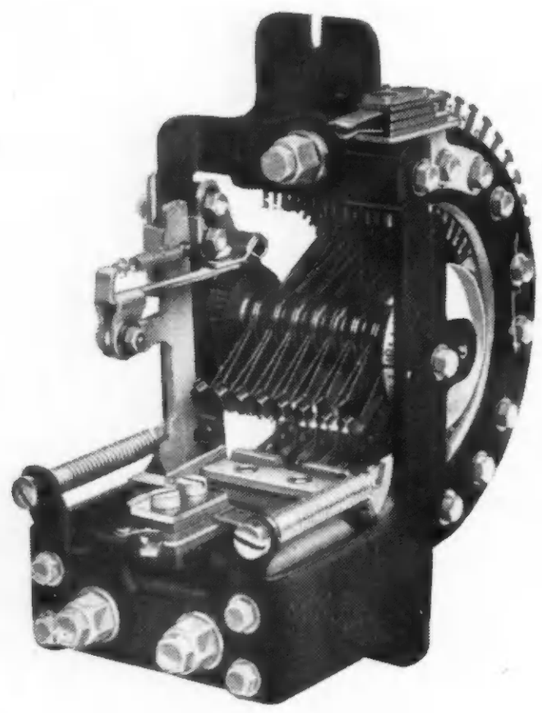


Fig. 3.—Uniselector switch.

Briefly, a transmitter is provided at the sending end, and this is connected by two line wires to a receiver at the distant cabin. On the transmitter are mounted push keys, and adjacent to each key is a label engraved with the description which the key controls. The receiver is fitted with the same number of labels, engraved to correspond with those on the transmitter, but instead of keys, several lamps are mounted adjacent to each label.

When the sending signalman wishes to describe a train, he pushes the key adjacent to the label engraved with the appropriate description. This sends a series of impulses over the two line wires to the receiving end, *e.g.*, one impulse for description A, two impulses for description B, and so on. If we suppose the key adjoining label F has been depressed, six impulses will be sent to the receiving end. Immediately the receiver has registered these, the "first" lamp adjacent to label F will light up. This display represents the description of the first train in section. If a second train is now described on the transmitter, the impulses will be duly registered by the receiver, and the "second" lamp adjoining the appropriate label will light up.

Generally, there are three types of instruments; terminal transmitters, retransmitters and terminal receivers. Each type of instrument varies in size and panel layout to suit local conditions and the scheme of operation, but the operating characteristics are similar.

The general terms applied to this type of apparatus, may be defined as follows:—

CODE.—A number of electrical impulses corresponding to a particular name or number, or to a special signal.

SET-UP.—To prepare the transmitting apparatus to send a code to the receiver.

TRANSMIT.—To send a code over line wires to a receiver. This may be effected with or without previous setting up.

RESET.—To restore the transmitting apparatus to normal, a code having been set up but not transmitted.

RETRANSMIT.—To transmit forward to the next cabin, the code of an indication displayed on a retransmitter receiver.

CLEAR.—To remove a displayed indication from a receiver, the train having left the section.

CANCEL.—To cancel a code in the receiver from the transmitting end, the code having been set up and transmitted in error.

UNISELECTOR SWITCHES.

The uniselector switch forms the basic part of a train describing equipment and its use enables the step by step impulse selection principle to be employed. These switches, of which one is illustrated in fig. 3, are identical with those used by the British Post Office for automatic telephony. The switch consists of several arcs of insulated contacts mounted in semicircular formation, each arc being traversed by a separate wiper, which connects the contact on which it is resting to an outgoing brush contact, *via*

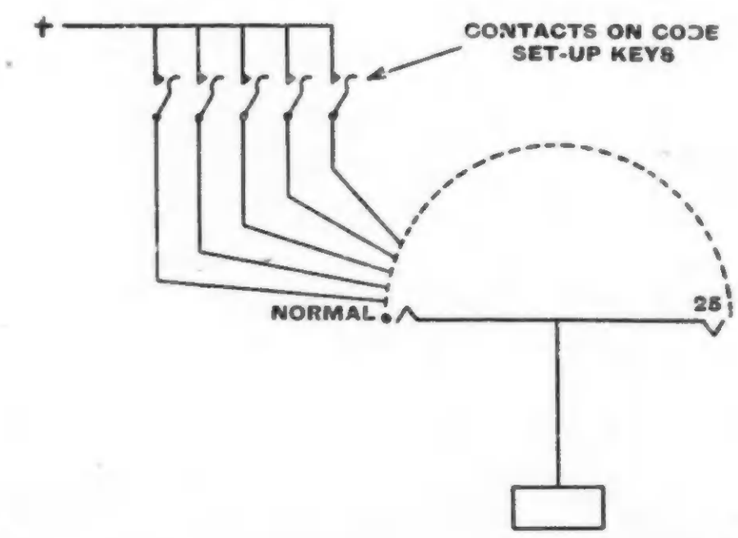


Fig. 4.—Diagram illustrating arrangement of transmitter.

a central slip ring. The wipers forming one assembly are insulated from each other, and rotate as a unit on a central spindle, movement being effected with a spring loaded pawl and ratchet mechanism operated by an electro-magnet.

When current is applied to the magnet coils, the pawl is lifted, but at this stage the spindle does not rotate; on current being removed, however, the pawl is released, and this forces the wipers to rotate one step forward. In this way, each current impulse received by the magnet advances the wipers one step, and thus connection is made to the required

contact by imposing the appropriate number of current impulses.

A contact is provided on the driving magnet which opens only when the pawl is lifted, and this is used to self drive to normal at the completion of an operation. The switches are provided with 25 contacts on each arc, and up to a maximum of 8 arcs may be fitted on one switch.

TRANSMITTERS.

The transmitter consists basically of one of these uniselector switches, from a bank of which connection is made to the code set-up keys. These keys mark a point on the bank, usually by extending the positive battery supply, and this determines the number of impulses to be sent out to the receiver. Fig. 4 illustrates this arrangement.

When the transmit condition is fulfilled, the switch begins to step in association with a corresponding switch in the distant receiver. Impulsing continues until the marked point is reached, when a time interval follows to indicate that the signal is completed. The switch is then self driven to its normal position without transmitting further impulses.

When a dual code, comprising a description and destination, has to be dealt with, the bank is divided into two sections with an intermediate normal position, the complete signal then consisting of two series of impulses with a definite time interval between them.

RECEIVERS.

The circuit elements of a typical receiver capable of storing four descriptions and displaying the first two, are shown in fig. 5. One uniselector is provided for each description, two of its arcs being indicated in each case to illustrate the method of providing for first and second train display.

The code receiving distribution switch directs the series of impulses to the correct receiving switches in turn. Thus, with the wipers of the distribution switch resting on the first bank contact, the first code will be directed to receiving switch A. On completion of the code, the distributing switch will advance one step in preparation for the next code, which will then be directed to receiving switch B, subsequent codes being directed in a similar manner to other receiving switches in turn.

The storage display sequence switch controls the order in which the stored descriptions are displayed. Two banks of this switch are indicated, one to control the display of the first train and one to control that of the second train. It will be noted that the contacts of the former bank are connected to receiving switches in order commencing with A thus :—A, B, C, D, whilst the bank contacts of the latter are connected to receiving switches in the same cyclic order but commencing with B thus :— B, C, D, A ; and in this way the first train display is maintained one storage ahead of the second train display.

When the first train passes out of the section, the storage switch displaying its description is self driven to normal, and at the same time the sequence switch is advanced one step ; B storage is then displayed as first train and C storage as second train. As trains

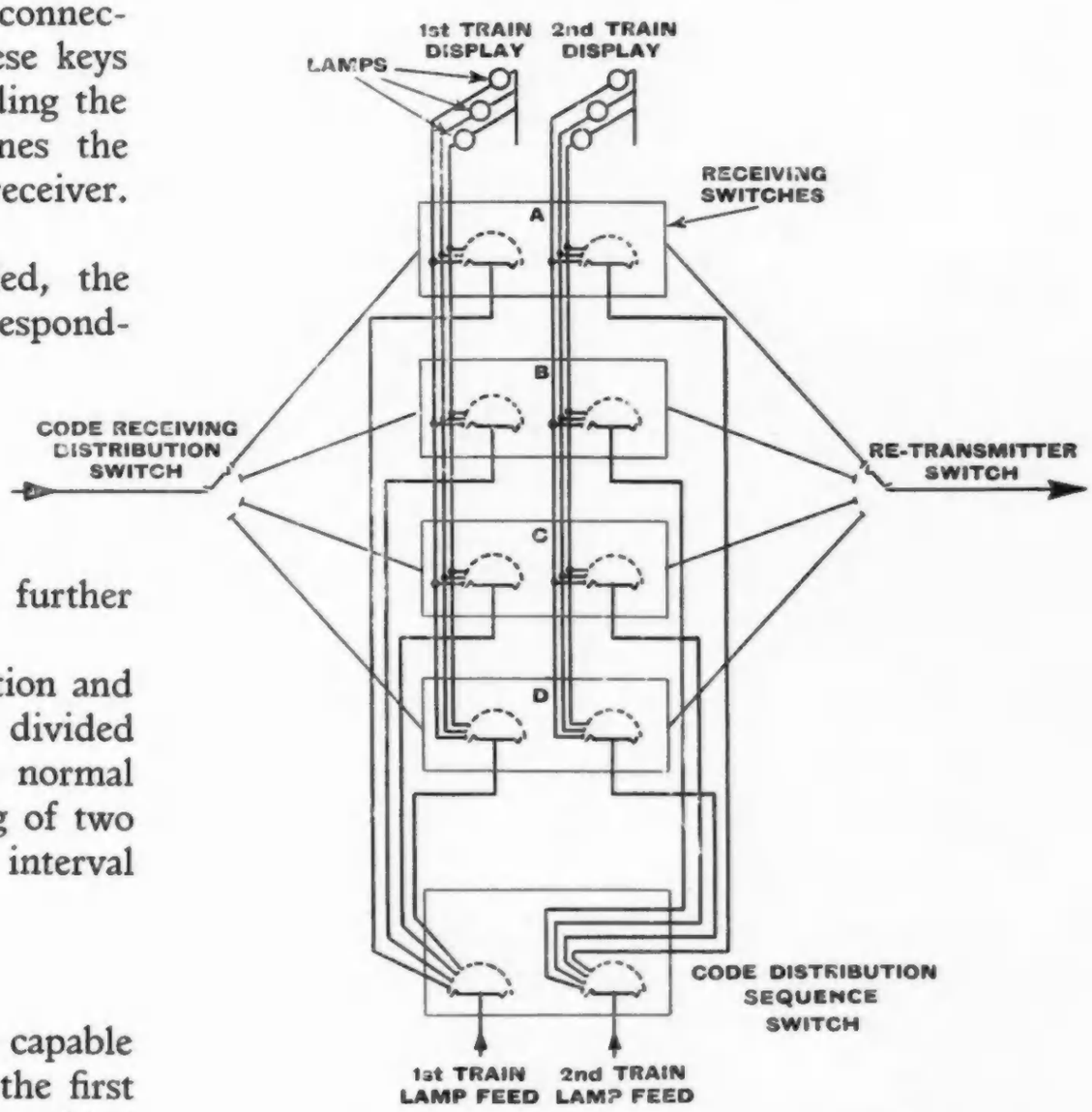


Fig. 5.—Circuit elements of a typical receiver.

leave the section, this process continues, the storages being stepped up in cyclic order. With this arrangement any number of the codes stored may be displayed by the provision of the appropriate number of switch levels.

Dual codes are dealt with by providing duplicate receiving switches, the first series of impulses for the description being directed to one switch, and the second series for the destination to another switch, the two switches then being treated as one set.

RETRANSMITTERS.

A retransmitter consists of a combined transmitter and receiver, the transmitter being provided with additional switch levels which are connected to the receiver as shown in fig. 5. These levels allow the position of the storage switches to be read off, enabling their equivalent codes to be transmitted forward as required.

CHECK BACK OF INDICATION.

As a check that the description displayed at the receiver is the same as that transmitted, a check-back system of impulsing may be employed, in which provision is made for each code sent out to be completely checked back by repetition from the receiver, the normal indication being withheld and a special indication given should for any reason the code received differ from that sent out. This is a patented and exclusive feature of the system under discussion.

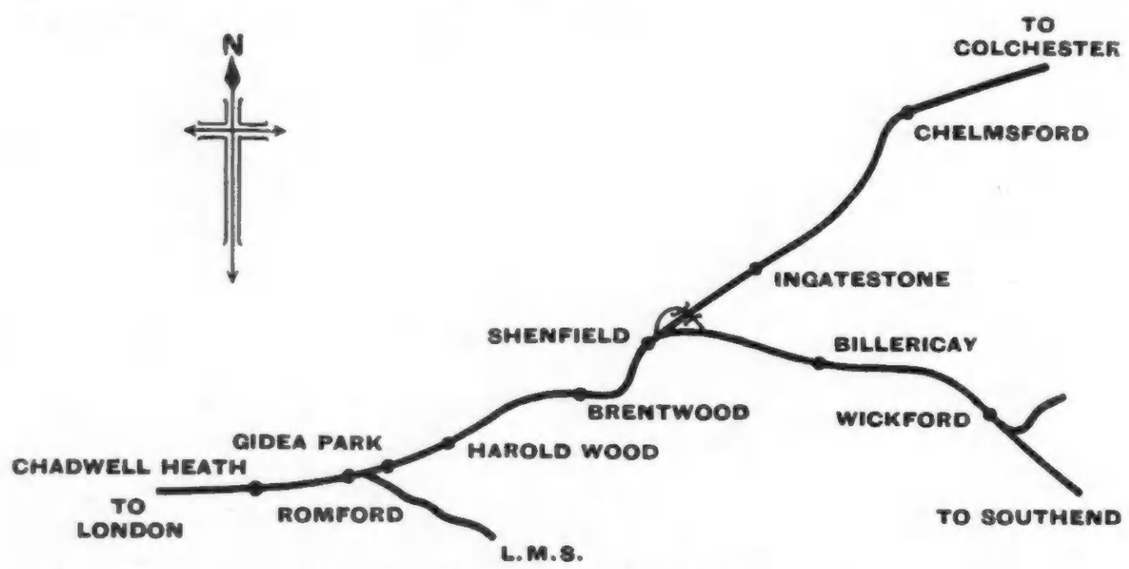


Fig. 6.—Section of the main line on the L. & N.E. Railway between Chadwell Heath and Chelmsford.

L. & N.E. RAILWAY INSTALLATION.

From the foregoing brief description of the principles of train describing, it will be of interest to pass on to an actual installation carried out by the Siemens and General Electric Railway Signal Company on an important section of the London and North Eastern Railway.

Of recent improvements carried out by this railway, the widening and re-signalling of this section between Gidea Park and Shenfield on the main line from London to Colchester is of particular importance.

Fig. 6 gives a geographical layout which includes the portion of the line to which train describers have been applied. The section from Romford to Gidea Park had already been widened and the recent improvements result in there now being, from Shenfield, four roads in the direction of Liverpool Street. Under the new signalling scheme the area is track-circuited throughout and provided with colour light signals. Considerable economies have been effected, the number of signal cabins having been reduced. The arrangements result in the section having a much increased capacity, providing for a three-minute headway of trains. There may thus be several trains under the control of a cabin at one time, and it is essential that the identity of each be made known to the signalmen accurately and quickly. Handling of normal traffic would be inefficient under the new conditions if old methods of describing were resorted to, whilst it would be practically impossible to deal with the heavy summer and holiday traffic. In consequence, modernisation was completed by the installation of new train describing equipment serving the section between Shenfield and Romford, a distance of about eight miles.

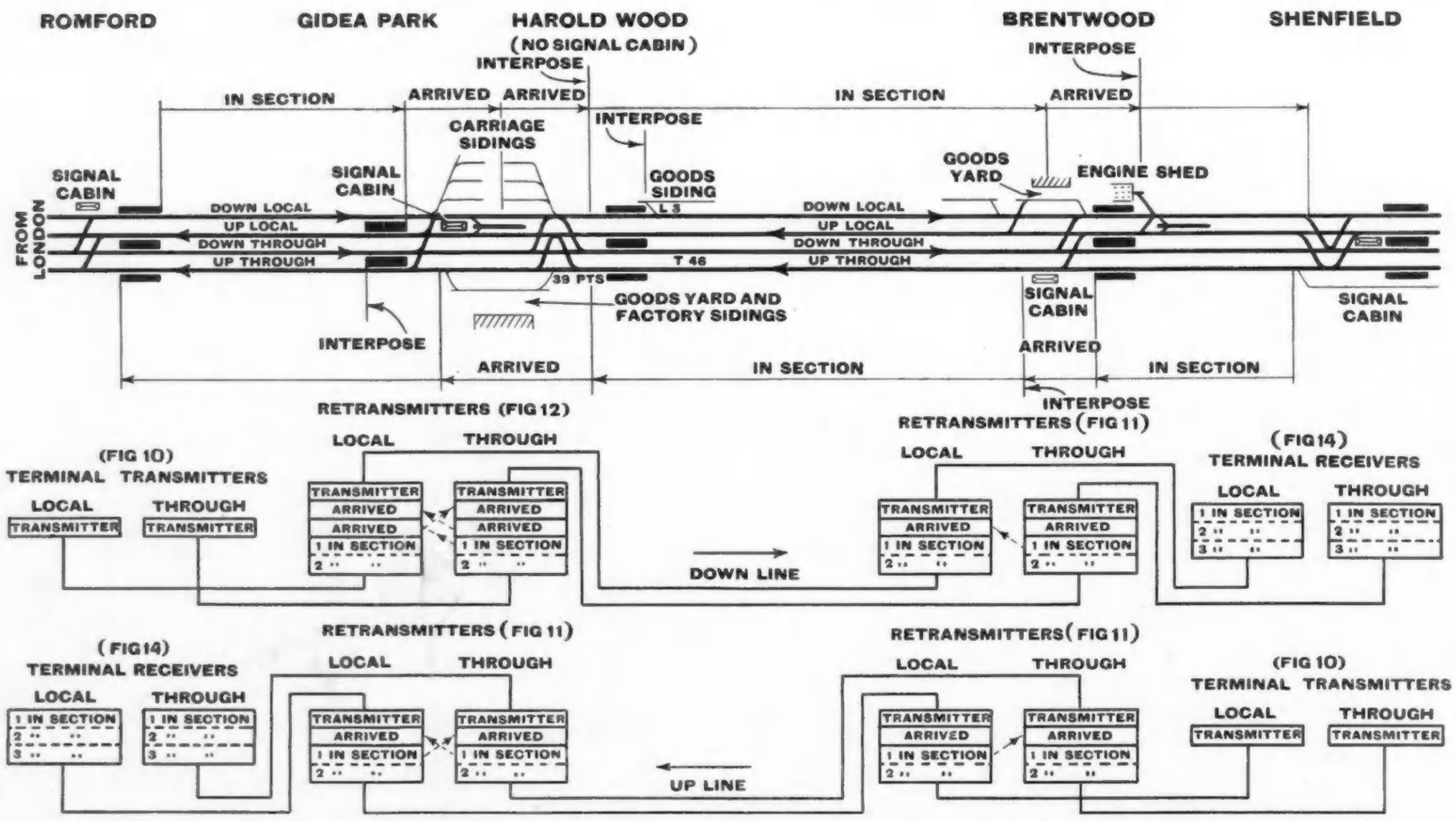


Fig. 7.—Plan of track and location diagram of train describing instruments.

Descriptions are set up by keys and displayed by lamps and comprise indication of the type of train and, as necessary, the destination or track occupied,

typical examples being "Express Passenger Main," "Express Passenger Southend," "Goods Class A Main," "Shenfield Local."

The track layout and location of all describing instruments are shown in fig. 7. It will be seen that separate instruments are provided for through and local services on both down and up lines. By operating the appropriate key a description is set up on a terminal transmitter, and transmission forward of impulses in a code assigned to the description set up is effected automatically by the progress of the train over the track circuits and by the signal controls. At the intermediate cabins at Brentwood and Gidea Park (figs. 8 and 9) the impulses are received and cause the appropriate description to be displayed. Retransmission to the next cabin is again automatically effected by the progress of the train. When the train leaves the describing area its description is automatically cleared down. Thus, after the initial setting up of a description, the operation is entirely automatic, and this is a prominent feature of the system.

To deal with trains crossing from one line to another the receiving panels of the retransmitters are sectionalised, the track up to a cross-over is termed "in section," and the track to the next cross-over "arrived," sets of receiving lamps being fitted on the panels and designated "in section" or "arrived" as required. In this way descriptions are progressed on the describing instruments as each cross-over is reached. For example, a train entering the down local road automatically transmits its description, as set up, to the "in section" receiving column of the down local retransmitter ahead. If the train now crosses to the through road its description is transferred to the "arrived" column on the down through instrument, or, if it continues on the same road, its description is transferred to the next "arrived" column on the local instrument. As the train proceeds, its description is advanced a further "arrived" column if there is another cross-over and subsequently, as it enters the section ahead, its description is cleared and retransmitted forward to the next cabin. These operations are repeated in this cabin and finally, when the train leaves the describing area, its description is cleared from the system. The foregoing outlines the operation for a train passing through the describing area on either the through or local lines, but, of course, a train may pass into a siding after entering the area. In this case the description is automatically cleared when the siding is reached. Similarly, a train may enter the tracks from a siding at one of the intermediate signal cabins. Its description is interposed by operating the appropriate key on the retransmitter, the code then being sent forward as the train progresses.

Fig. 8.—Signal box at Brentwood containing train describing equipment shown in fig. 14.

Fig. 9.—Signal box at Gidea Park. The train describing equipment installed is shown in the frontispiece on page 66 of this issue.

TRANSMITTERS.

Fig. 10 illustrates the through transmitter at Romford, and this is a typical example of the terminal

transmitters in this installation. On learning the class of train approaching his section the signalman depresses the set-up key corresponding to the description of the train. This operation causes a code of impulses to be stored in the apparatus and lights the set-up check lamp adjacent to the key depressed. When the train enters the section the

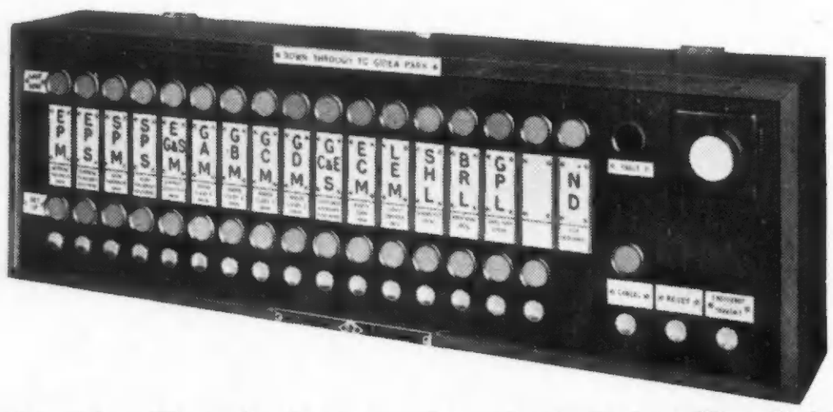


Fig. 10.—Terminal transmitter installed at Shenfield and Romford signal cabins.

code of impulses is automatically sent forward, the set-up lamp is extinguished and the lamp above the label glows to give a visual indication of the description as the "last train sent." Depression of the appropriate set-up key is all that is required of the signalman, and thus the sending operation requires a minimum of time and practically eliminates possibility of error. Should, however, an incorrect description be set up and sent, it may be cancelled by operating the cancel key provided on the transmitter. When the key is depressed an audible warning and visual indication are given at the receiving end. The signalman there acknowledges receipt by depressing his cancel key, whereupon cancellation is completed and an indication given in both cabins.

Fig. 11.—Up local retransmitter at Gidea Park.

RETRANSMITTERS.

The up local retransmitter at Gidea Park is illustrated in fig. 11, whilst fig. 12 shows the down local retransmitter in the same cabin. These also are typical of this pattern of instrument. Each is fitted with set up keys for interposing. The down local describer is provided with sets of receiving lamps to deal with a route having two cross-overs, and the up local describer with sets of lamps for one cross-over, descriptions as received being passed progressively from one set to another as the train progresses. A brief consideration of typical traffic moves will clearly show the manner in which the retransmitters operate.

On being advised of an approaching train from the direction of London, the Romford signalman sets up its description on the appropriate transmitter. This description remains set up until the Romford starting signal lever is reversed, whereupon it is automatically transmitted forward to Gidea Park, where it is stored and in turn displayed in the "in section" column of the retransmitter associated with the instrument at Romford.

Reference to fig. 13, which is a detailed layout of the Gidea Park area, will show that a through line train may take one of the following routes on leaving Gidea Park Station :—

(1) With signal 24 off, continue on the through road to splitting signals 25-15. When this route is taken the description is displayed in the row of lamps labelled "arrived signal 25."

(2) With signal 38 off, cross over to the local road and proceed to signal 19. In this case the description is transferred from the through line retransmitter to the local retransmitter's lamp set labelled "arrived signal 19."

(3) With signals 30 or 28 off, terminate in the centre or carriage sidings. The description is then automatically cleared from the system.

If it be assumed that the train had taken route (2)

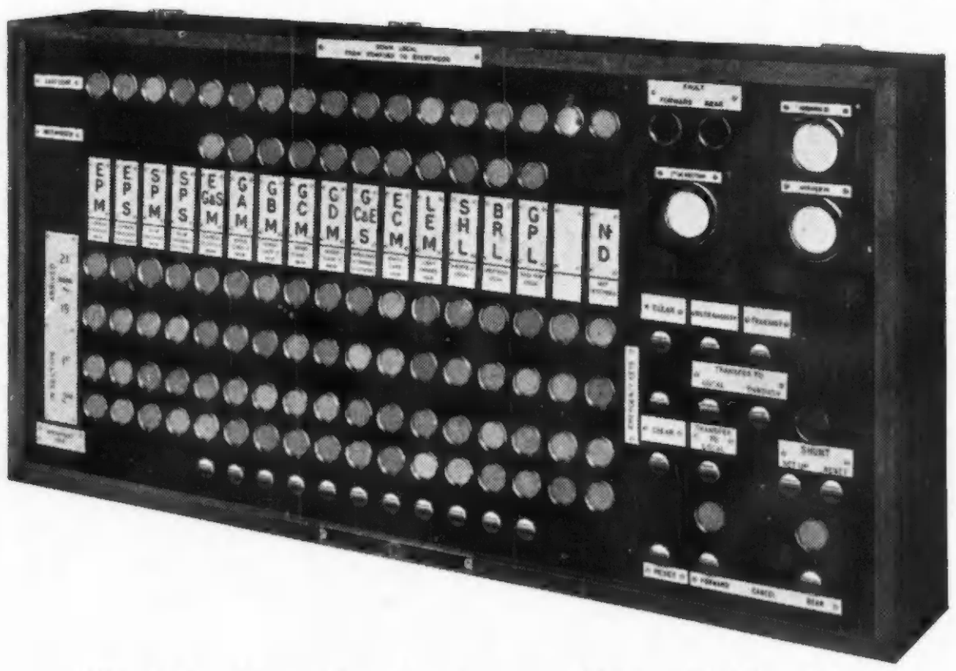


Fig. 12.—Down local retransmitter at Gidea Park.

its description will be displayed in the "arrived signal 19" set on the local instrument (fig. 12).

The train can now proceed as follows :—

(4) With signals 19 and 20 off, continue on the local line to signal 21. Its description is then displayed in the lamp set labelled "arrived signal 21."

(5) With signals 19 and 26 off, cross over to the through line again until signal 27 is reached. The description is then transferred back to the through line retransmitter and displayed in the "arrived signal 27" lamp set.

Immediately a train on the local line passes signal 21 or, on the through line, signal 27, its description on the retransmitter at Gidea Park is cleared from the "arrived" set and displayed as "last train sent," and the impulse code is automatically transmitted to Brentwood.

Traffic moves on the up line control the displays on the up retransmitters in a similar manner.

Reference has been made to the possibility of trains entering the tracks at intermediate points. The description of any such train is set-up by operating an interpose key on the appropriate retransmitter. This illuminates a corresponding check lamp immediately above the code labels, and the description is automatically transmitted as the train goes forward.

ADVANCED RETRANSMITTING.

The retransmitter for the up through line at Gidea Park is fitted with an advanced retransmitting feature to cope with special traffic conditions. Normal retransmission of impulses from Gidea Park to Romford would be effected when a train passes signals 44 or 49 but, owing to the short distance between these two cabins, the signalman at Romford would receive insufficient warning of the approach of a fast train. Consequently arrangements are made for the description of a train on the through line to be retransmitted to Romford before the train passes Harold Wood station. The description is displayed on the through or local line instrument at Romford whilst displayed as "train in section" at Gidea Park, but it is not cleared from Gidea Park until the train actually arrives at the cabin. This arrangement therefore permits trains to be described to more than one cabin ahead, and provides yet another example of the ease with which such requirements are readily satisfied by this train describing equipment.

TERMINAL RECEIVER.

The up through receiver at Romford is illustrated in fig. 15. Similar instruments are employed on the local line at Romford and the local and through lines at Shenfield. Three sets of lamps serve to display descriptions of the first three trains in section, subsequent descriptions being stored in the apparatus. When the first description is cleared by the train passing over the clearing track the second description becomes the first, the third becomes the second and the first of the descriptions stored is displayed as the third train in section.

To complete the outline of the operation, mention may be made of the measures taken to guard against misunderstanding arising out of failure, for any reason, on the part of a signalman to send the description of a train entering the section ahead of his cabin. This contingency is provided for by counting all trains as they pass one of the advance

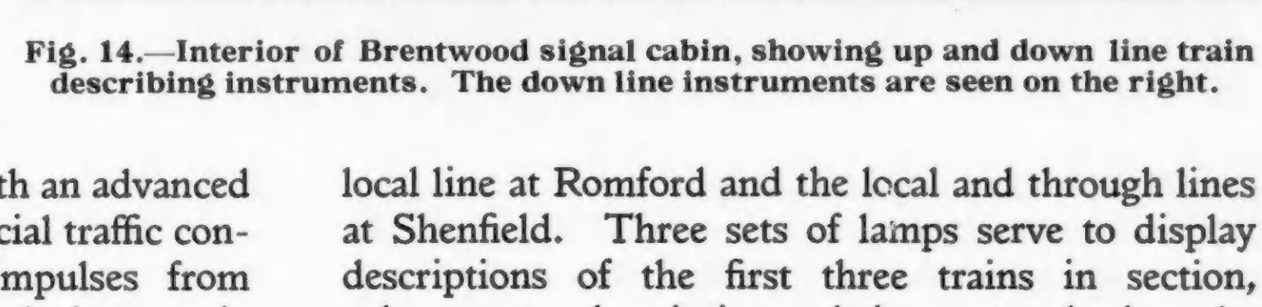


Fig. 14.—Interior of Brentwood signal cabin, showing up and down line train describing instruments. The down line instruments are seen on the right.

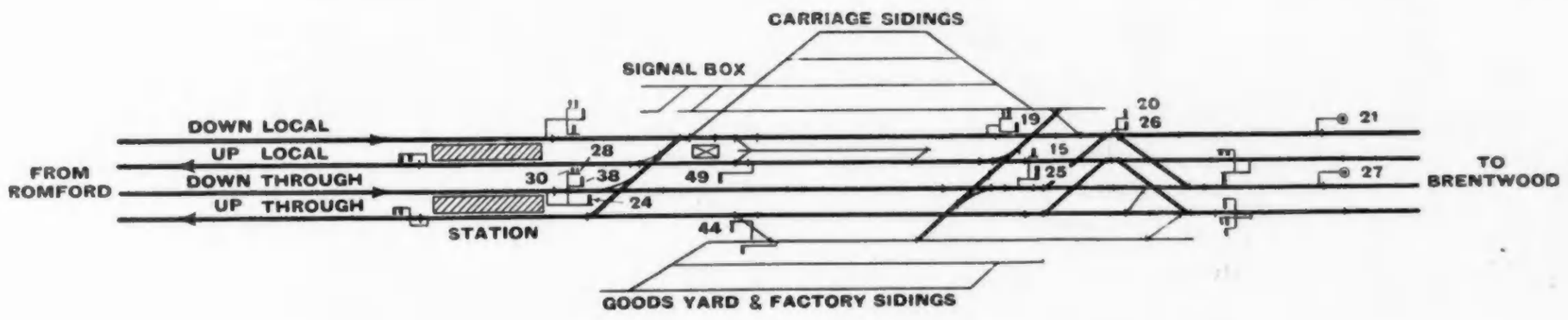


Fig. 13.—Track layout at Gidea Park.

tracks, and if a description is not available for any particular train a specially reserved code of impulses is automatically sent forward and causes a lamp labelled "not described" to glow on the instrument

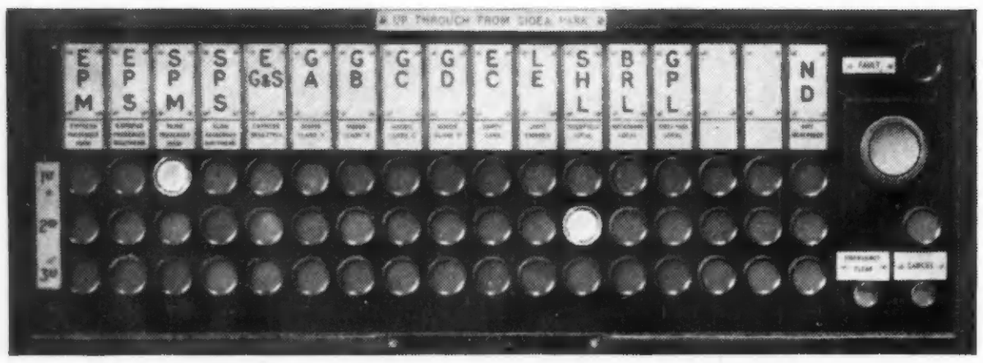


Fig. 15.—Terminal receiver at Romford. A similar instrument is installed at Shenfield.

ahead. On receipt of this indication the signalman institutes the necessary enquiries.

LINE WIRES.

In this installation, simplicity, ease of maintenance and the greatest measure of overall economy have been achieved by employing one wire per track and one common return, that is, a total of five wires for the four tracks.

CONTROL APPARATUS.

A control cabinet, consisting of uniselectors and relays is provided at each of the Romford and Shenfield cabins and two at both Gidea Park and Brentwood. Fig. 16 illustrates a typical cabinet. The relays and uniselectors are mounted on hinged gates and all outgoing connections are terminated on the back panels of the cabinets. Relays are fitted with duplicate contacts, and the provision of covers and the special design of the cabinets prevents the ingress of dust. Fuses in the battery feed circuits are fitted in a separate case mounted on the top of each cabinet, thus facilitating the replacement of fuses without disturbing the control apparatus.

A storage battery of 20 or 40 ampere hours capacity is provided in each cabin to supply the control apparatus at a nominal 50 volts. The indicating lamps are of the 12 volt, 4 watt, metal filament type, and are fed through transformers from the A.C. mains. Duplicate mains supplies are available at Shenfield and Brentwood, but not at Gidea Park and Romford; hence at these two latter cabins stand-by batteries are automatically switched into circuit if the supply should fail.

The installation is outstanding by virtue of the simple and efficient method employed for automatically dealing with the many varied traffic moves on this busy section of line, and is representative of the equipment which may be provided in many dense areas to assist signalmen in the efficient handling of traffic.

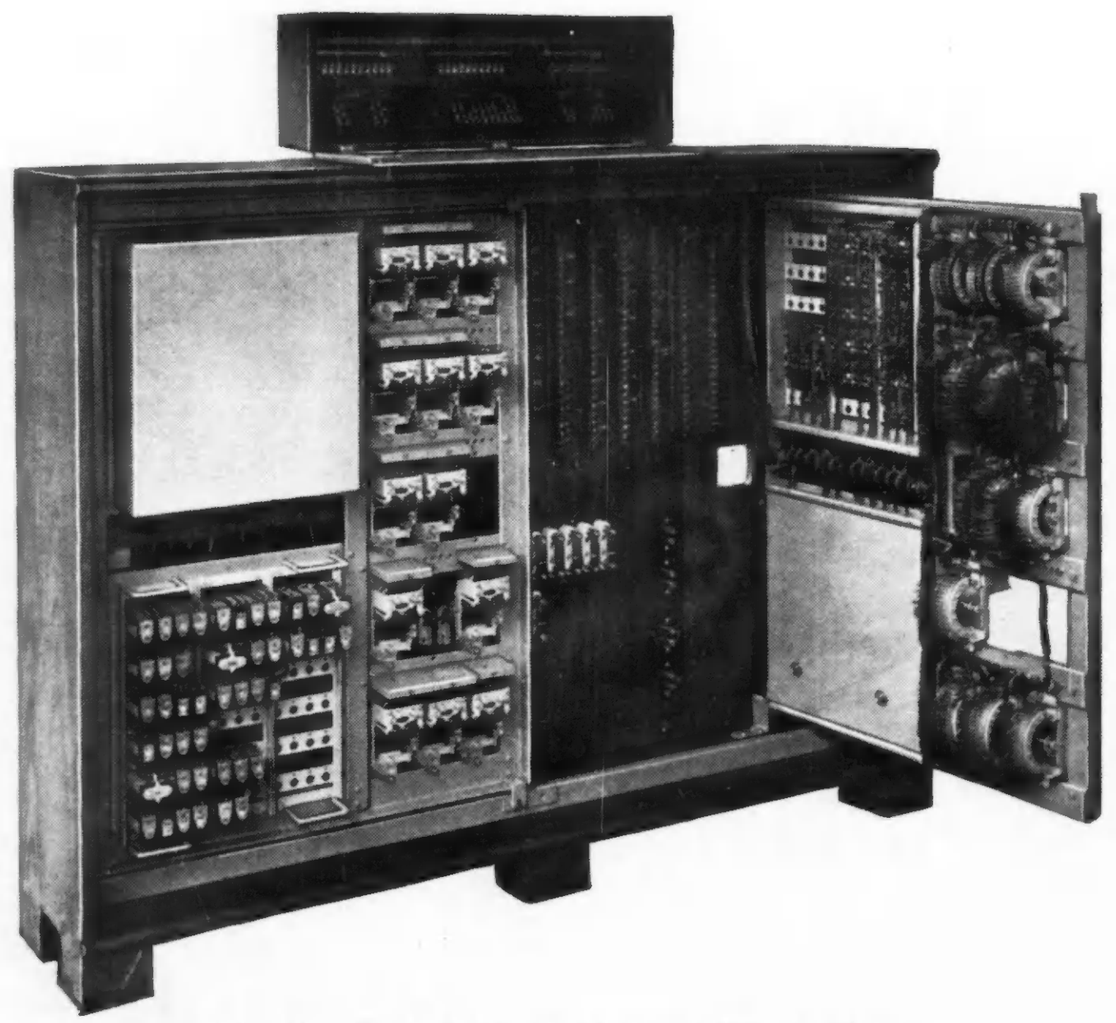


Fig. 16.—Typical control apparatus cabinet.

Generation, Distribution and Use of Electricity on Board Ship.*

By C. WALLACE SAUNDERS, A.M.Inst.C.E., A.M.I.E.E., M.I.Mar.E.,
Manager, Marine Dept. of The General Electric Co., Ltd.

H. W. WILSON, A.M.I.E.E.,
and
R. G. JAKEMAN, D.Sc., M.I.E.E.,
} Witton Engineering Works.

INTRODUCTION.

WHEN the design and construction of a new vessel are under consideration the use of electricity for auxiliary purposes is now taken as a matter of course. Its use for propulsion purposes is also in many cases given very serious thought.

Electricity has been used in the British Navy for various purposes since 1874, but although in the merchant service it has been used for lighting for many years, it is only since the advent of the Diesel engine and the consequent elimination of steam from a large number of vessels that electricity has been used extensively for other purposes. To-day, almost all auxiliary machinery—from the windlass in the bows, through the engine room and hull, to the steering gear in the stern—is, in most important ships, electrically operated.

Great progress has been made with electric propulsion both in this country and abroad, and by 1931 the power of the electrically-propelled ships of all nationalities exceeded 1,000,000 s.h.p. During 1931, British yards alone turned out first-class passenger-carrying tonnage totalling 70,000 s.h.p. Table 1 gives details of the more important of these vessels.

Since 1931, shipbuilding has suffered, in common with most other industries, from the prevailing depression. Nevertheless, the largest vessel turned out in 1933, namely the "Queen of Bermuda," is electrically propelled.

When the type of propelling and auxiliary machinery is under review the following requirements (in addition to those of efficiency and first cost) must be studied in all their aspects. (*a*) The available space must be utilized to the greatest advantage. (*b*) The machinery must withstand the arduous conditions of marine service at a minimum cost for maintenance. (*c*) The vessel must be

* Paper read before the Institution of Electrical Engineers, 22nd Nov. 1934.

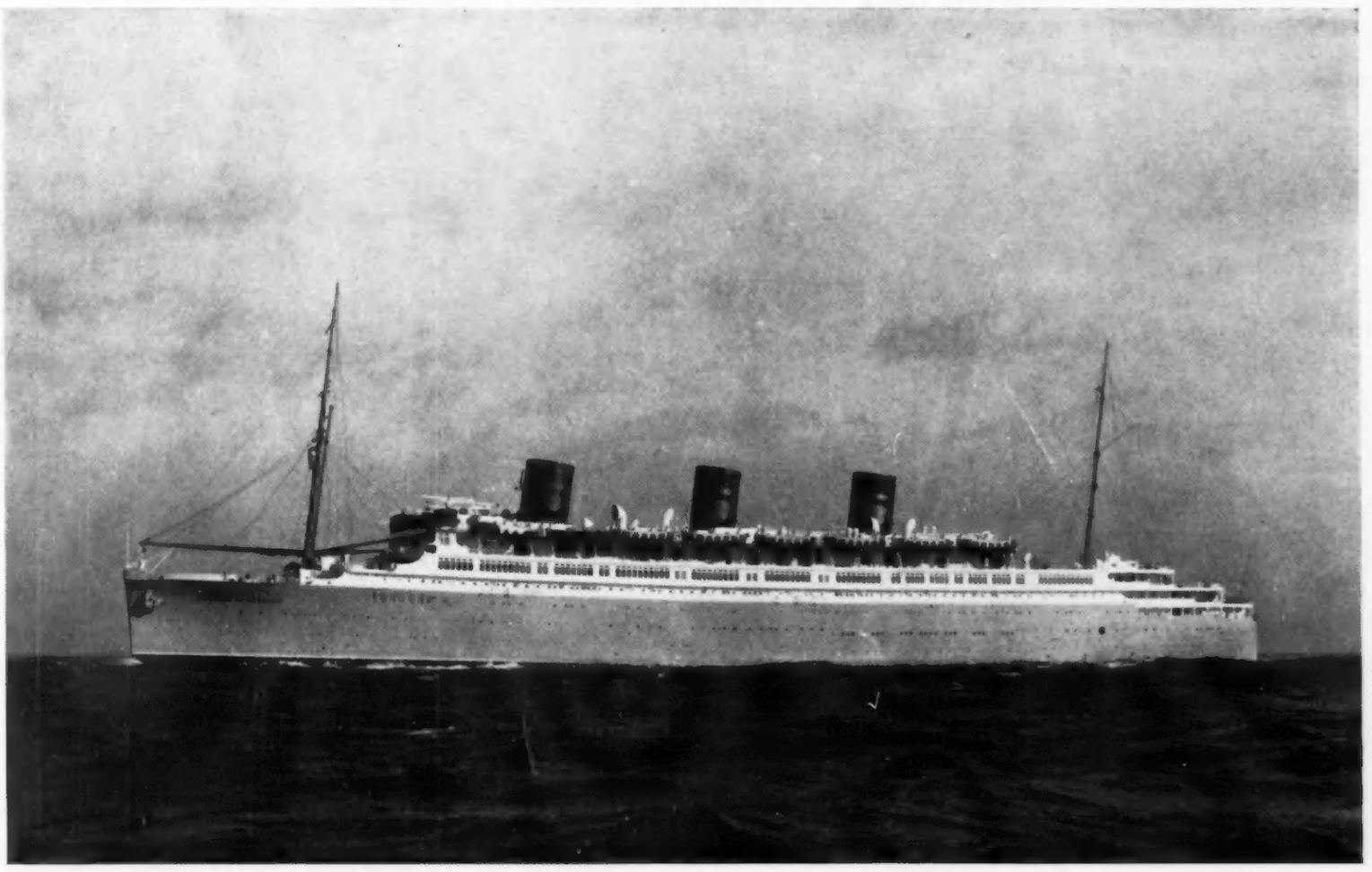


Fig. 1.—The quadruple screw turbo-electric liner, "Monarch of Bermuda."

capable of being quickly manœuvred in and out of its berth, making a fast run from port to port with sufficient reserve of power to enable it to make up time lost through bad weather or on account of a late start due to delays in connecting services. It must be capable of a quick turn-round at each end of the voyage.

A passenger liner may be required to spend a certain portion of its life in cruising at reduced speeds, and during the regular voyage to maintain a varying speed schedule over sections of the run.

On certain types of cargo vessels the amount of power required for auxiliary purposes and cargo handling may be very large, amounting to an appreciable percentage of that required for propulsion.

In the large insulated holds of vessels carrying refrigerated cargo, which in value often exceeds that of the ship itself, it may be necessary to maintain the temperature constant to within 1 deg. F. throughout the voyage.

That electrical operation can satisfactorily fulfil all of the demands made by these services is an established fact.

GENERATION.

TYPES OF VESSEL AND NATURE OF LOAD.

The various types of vessel in service may roughly be divided as follows :—

Large passenger liners.—These may include the largest ships afloat. Electrical power may be used for propulsion, and nowadays is used almost invariably for all auxiliary purposes, *e.g.*, hull machinery, engine-room machinery, lighting, heating, cooking and ventilating.

Intermediate liners.—These comprise combined cargo and passenger vessels which for propulsion employ Diesel engines, geared turbines, or steam reciprocating engines; also electrically-driven auxiliaries, electric lighting, etc.

Large cargo vessels.—These may be propelled by geared turbines, steam reciprocating engines, or Diesel engines, and carry an enormous amount of refrigerated cargo. The refrigeration equipment, and most of the other auxiliary services such as lighting, are practically always electrically operated.

Small cargo vessels.—These include self-unloading vessels (which are also sometimes electrically propelled). All have electric lighting, and in most cases the auxiliaries are electrically operated.

Tugs and small craft.—In vessels of this type electric lighting is employed, and electric propulsion is becoming extensively used.

Trawlers.—These provide an extensive field for the increasing use of electricity for all purposes. Some trawlers are already equipped with electric trawl winches and electric lighting.

It is literally true that the electrical equipment of a modern ship covers practically the whole range

TABLE 1.

Name of Vessel	Owners	Propulsion generators	Propulsion motors.	Auxiliary generators	Gross tonnage
Strathnaver* ..	Peninsular and Oriental Steam Navigation Co.	2 turbines, 10,700 kW each	2 3-phase synchronous, each 14,000 s.h.p.	3 turbines, 750 kW each 1 turbine, 400 kW	22,540
Strathaird* ..	Peninsular and Oriental Steam Navigation Co.	2 turbines, 10,700 kW each	2 3-phase synchronous, each 14,000 s.h.p.	3 turbines, 750 kW each 1 turbine, 400 kW	22,540
Rangatira* ..	Union Steam Ship Co. of New Zealand	2 turbines, 5,300 kW each	2 3-phase synchronous, each 6,750 s.h.p.	3 turbines, 350 kW each	6,152
Monarch of Bermuda*	Furness, Withy and Co.	2 turbines, 7,500 kW each	4 3-phase synchronous, each 4,750 s.h.p.	4 turbines, 750 kW each	22,424

* Built by Messrs. Vickers-Armstrong, Ltd.

Fig. 2.—A general view of four 750 kW auxiliary generators in a modern liner.

of present-day electrical products. Table 2 gives details of the numbers, types, and duties, of the electrical machines and apparatus installed in a typical 20,000-ton passenger liner.

TYPES OF GENERATOR AND SYSTEMS OF SUPPLY.

The following types of generator and systems of supply are generally adopted.

For propulsion.—Turbo-electric alternating-current; Diesel-electric direct-current; exhaust turbo-electric alternating-current and exhaust turbo-electric direct-current for extra power; Diesel-electric extra power in vessels propelled solely by Diesel engines, for electric starting and manœuvring of main engines to "slow ahead" and "slow astern."

For auxiliary purposes.—Geared turbo-electric direct-current (fig. 2); Diesel-electric direct-current; steam reciprocating sets direct-current.

For turbo-electric a.c. propulsion, 3-phase turbo-alternators running at 3,000 r.p.m. are generally employed. The supply voltage may be as high as 10,000 volts, but is usually about 3,000. The alternators are as a rule provided with closed-circuit coolers, sea water being circulated as the cooling medium. In order to minimize trouble due to condensation whilst the alternators are not in use, small electric heaters of from 2 to 3 kW capacity may be embodied in the frames of the machines. Excitation is obtained from the ship's auxiliary supply *via* either negative boosters or motor-generator sets.

In the case of Diesel-electric d.c. propulsion, the voltage may be as high as 1,200 or 1,500 volts. In large installations there are usually several generators in series, and double-armature motors are employed. The main generators are normally connected in series with the double-armature propelling motor, but switching means are provided so that in the event of a generator or half-motor being out of commission for any reason the unit in question can be isolated and the vessel may proceed at reduced speed.

The question of drive for auxiliary generators naturally depends largely upon the type of propelling machinery in use. In cases where steam is used for propulsion, the auxiliary generators may also be steam-driven. There is much to be said, however, for Diesel-driven auxiliaries even if steam is used for propulsion, as the Diesel-driven sets can be run at any time whether the boilers are in use or not.

The auxiliary generating plant may vary from several 1,000-kW generators for a large liner to a 1-kW lighting set for small craft. The generators

TABLE 2.

Details of Electrical Machines Installed on a 20,000 ton Turbo-electric Passenger Liner.

Duty	Type	Number	Total h.p.	Remarks
Propelling machinery	Turbo-alternators	2	20,100	3,000-volt
	Propelling motors	4	19,000 s.h.p.	3,000-volt
	Ventilating fans	4	84	For propelling motors
Dynamos	Boosters	3	125	For excitation
	Main generators	4	4,020	
	Emergency generators	1	67	
Pumps	Main circulating	2	320	
	Auxiliary circulating	3	195	
	Bilge, ballast, sanitary, and general service	6	144	
	Main extraction	2	50	
	Auxiliary extraction	3	21	
	Sludge	1	4	
	Forced lubrication (oil)	2	13	
	Heeling tank	2	16	
	Hot fresh water	1	2½	
	Laundry and swimming bath	2	1	
	Cooled water	1	1½	
	Fresh water	2	36	
	Oil-fuel transfer	2	54	
	Cargo fresh water	1	18	
	Watertight doors	2	10	
Steering gear	Steering-gear motors	2	84	
	Auxiliary steering-gear motors	1	7½	
Deck machinery	Windlass motor	1	150	
	Windlass booster	1	90	
	Capstan motors	4	300	220-volt, direct current
	Capstan boosters	4	236	220-volt, direct current
	Winch motors	4	96	220-volt, direct current
	Baggage winches	2	14	220-volt, direct current
	Warping winch	1	7	220-volt, direct current
	Boat davits	8	120	220-volt, direct current
Fans	Forced draught	8	136	220-volt, direct current
	Engine-room ventilation	9	122	220-volt, direct current
	Accommodation ventilation	104	248	220-volt, direct current
Refrigeration	Compressors	4	220	220-volt, direct current
	Brine pumps	5	40	220-volt, direct current
	Circulating pumps	4	16	220-volt, direct current
	Miscellaneous	12	10	220-volt, direct current
Laundry	Washing and ironing machines, etc.	7	15	220-volt, direct current
Lifts	Variable-voltage motor-generator sets	4	26	220-volt, direct current
	Passenger lifts	3	31½	220-volt, direct current
	Engineers' lifts	1	5	220-volt, direct current
	Stores, cargo, and service lifts	7	56	220-volt, direct current
General	Sewage compressors	2	110	220-volt, direct current
	Dancing-space dimmer	1	12 kW	220-volt, direct current
	Miscellaneous	21	70	220-volt, direct current
	Cabin fans	650	—	Fractional h.p.

are usually compound-wound, and arranged for parallel running.

Where Diesel-driven generators are employed for propulsion the auxiliary generators are usually run in tandem, *i.e.*, coupled to the same shaft as the propulsion generators, and equipped with automatic voltage regulators. The auxiliary generators supply excitation in addition to the auxiliary power and lighting load.

If the main engines are of the direct Diesel type Diesel-driven auxiliary sets are employed. Ships of this type have been equipped with waste-heat boilers heated from the main engine exhaust, combined with a steam-driven auxiliary generator.

In order to supply power when the auxiliary generators are not running, a small direct-driven set is usually installed. To meet Board of Trade requirements on passenger ships a small oil engine driven generator called the "emergency generator" is installed also, always on an upper deck.

Constructional Features of Generators.

In the main constructional features, generators for use on board ship follow the practice which has been adopted for land work and has proved successful for many years.

Particular care has to be given to the design from the point of view of accessibility and facility for overhaul, on account of the limited head-room and space available.

All machines must be specially impregnated to withstand tropical conditions. Protection must be afforded against dripping moisture.

The generators may have to run in a fume-laden or oil vapour-laden atmosphere, and—particularly in the case of d.c. machines—it is necessary for the design to be so arranged as to prevent the accumulation of dirt and oil at inaccessible points where they can lie unsuspected and eventually lead to failure.

As a.c. generators for propulsion may run for prolonged periods at any speed from dead slow to full, critical speeds must be avoided within this range.

Lubrication must be arranged to function satisfactorily at all speeds and with a roll or list of $22\frac{1}{2}^{\circ}$.

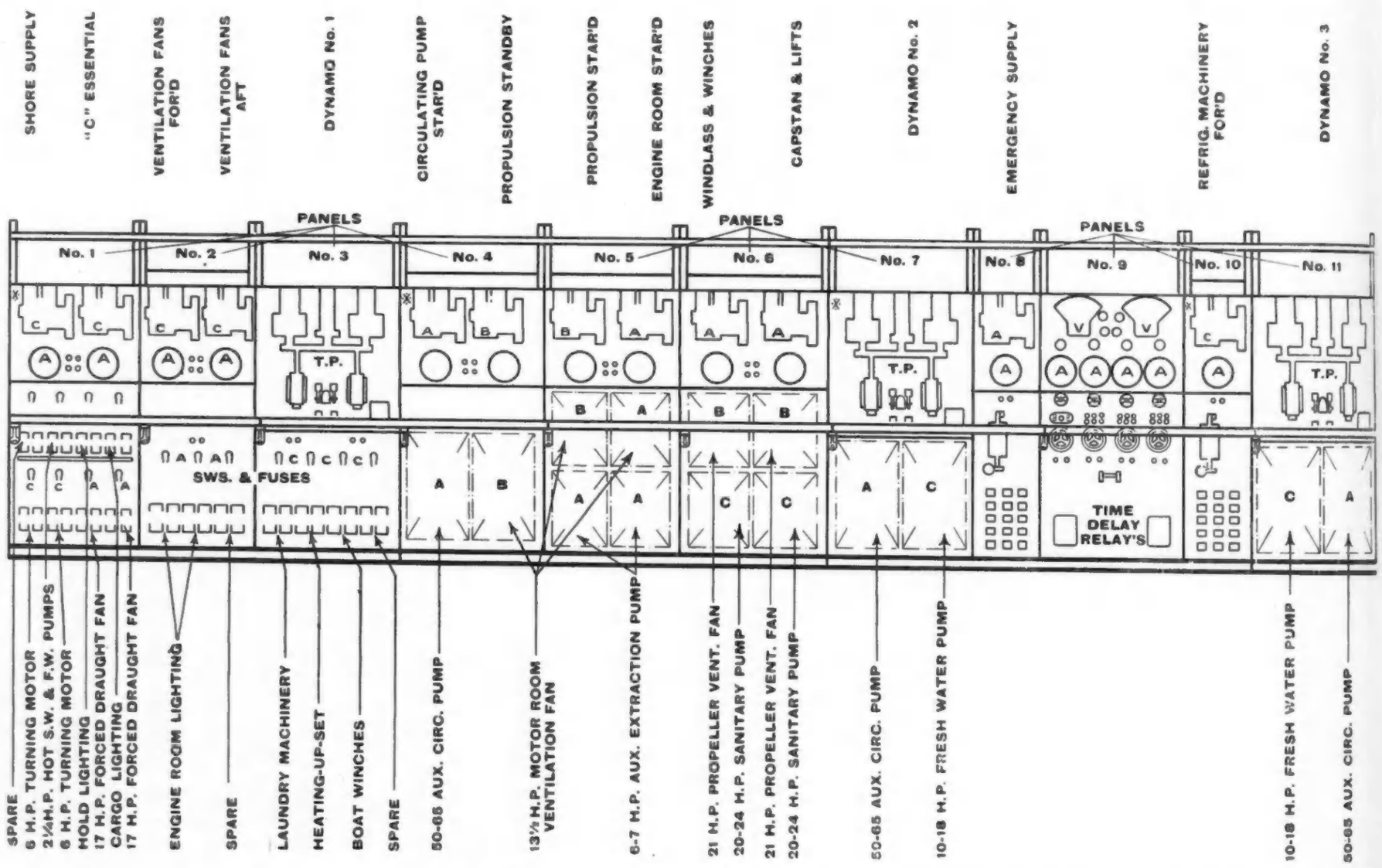


Fig. 3.—Outline arrangement of a main-direct current switchboard installed in a modern liner. Circuit to which circuit mark is co

The utmost possible freedom from noise and vibration is essential.

Unfortunately, perhaps, from the point of view of an ideal engineering lay-out, the machinery spaces are usually cut down to an absolute minimum: the design must therefore of necessity be as compact as is compatible with the foregoing requirements. Naval architects and consulting engineers can assist materially in this direction by ensuring that the machinery spaces are adequate and are efficiently ventilated and illuminated.

Auxiliary Supply.

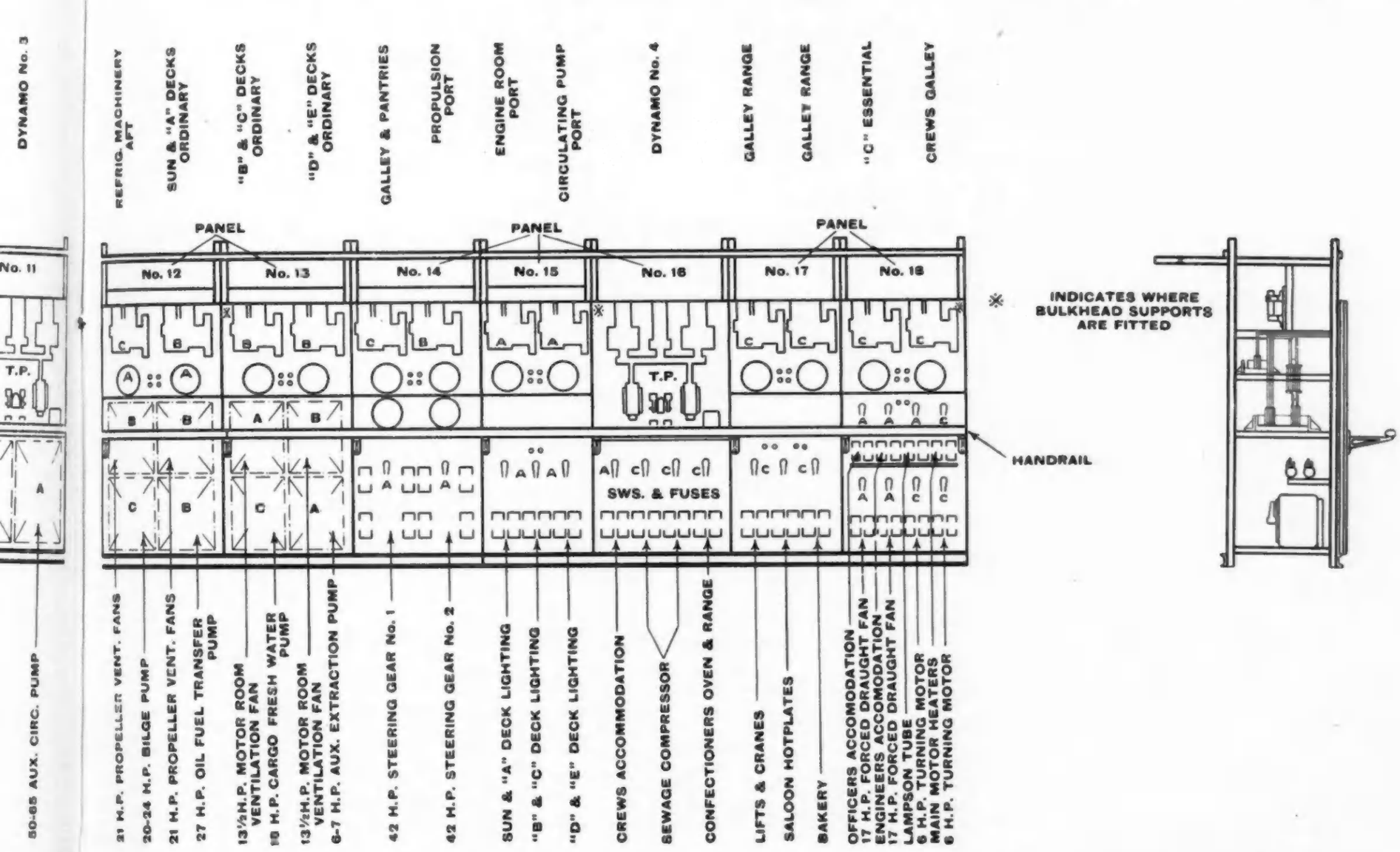
The auxiliary supply for power and lighting may be at either 110 or 220 volts, and in some cases 440 volts for power purposes. Direct current has been

almost universally employed for auxiliary purposes, even in vessels where alternating current is used for propulsion. Alternating current has in a few cases been tried, but so far there has been no great tendency towards its general use.

DISTRIBUTION AND USE.

SWITCHBOARDS.

The main generators and feeders are generally controlled from a main switchboard (figs. 3 and 4) situated in close proximity to the generators, and ring-main feeders are taken to the various sub-switchboards throughout. It is usually necessary for the load to be divided deck by deck, and provision must be made for alternative supplies to essential circuits.



Circuit marked "L" denotes links for ring mains. Letters A, B or C indicate category of essential tripping circuit is connected.

It must be appreciated that certain services such as emergency lighting, steering gear, lubricating-oil pumps, and refrigerating machinery, must be maintained at all costs. The circuits are therefore divided at the main switchboard into two categories—essential and non-essential.

Protection is afforded by means of a non-essential tripping system. In one form of this, auxiliary tripping busbars are run throughout the main switchboard, these busbars being energized through time-delay relays. In the event of an overload on the main dynamos, a contact is made through an overload relay. If the overload is maintained for, say, 2 sec., a time-delay relay makes its tripping contact and one set of tripping busbars is energized. This trips all the circuit breakers connected to this particular set of busbars, and all non-essential circuits are thus disconnected. Should the overload persist, a second time-delay relay operates on a second set of busbars after a further 2 sec., and all circuits of secondary importance become disconnected only vital circuits being left alive. If the overload is still maintained after a further 2 sec., another time-delay relay will trip out the generator circuit-breakers, and, of course, the remaining circuits with them. It is of interest to note that the adoption of this or a similar scheme may effect a considerable saving in running costs, as the generators can be safely run at about full load capacity without endangering the continuity of supply to essential services. Consequently a smaller number of generators can be in use at any particular time, and those in use operate at maximum efficiency.

The generator circuit-breakers are usually equipped with overload and reverse-current protection, the former arranged to operate at a high value in case of a serious short-circuit (which would in any case render impossible maintenance of the supply), and the latter protecting against a failing engine or generator.

SUB-SWITCHBOARDS.

Sub-switchboards are installed where required throughout the ship, to allow of economy in cabling. A sub-switchboard should always be installed in

the refrigeration engine room because it is desirable, owing to the fine limits of speed variation required, that the control of the compressors, brine pumps, and circulating-water pumps, should be placed in the most convenient position in order to facilitate ease of operation by the refrigeration engineers.

ENGINE-ROOM AUXILIARIES.

Engine-room auxiliaries (fig. 5) comprise pumps, compressors, and fans, most of which have to function with unfailing reliability throughout the voyage, often in temperatures varying between zero and 140°F. In view of the possible high ambient temperature it is desirable that the rating should be very liberal.

Vertical-spindle centrifugal pumps are generally used in most modern ships, and there is much to commend this type of machine. It occupies a minimum of space, is easily protected from dripping moisture, and is readily accessible.

HULL MACHINERY.

A large proportion of the hull machinery, such as lifts, fans, and ventilating units, is situated in close proximity to either the passenger accommodation, the navigating bridge, or the wireless room. Hence it will be readily understood that the greatest requirement apart from reliability is the maximum possible freedom from noise, vibration, magnetic hum, and inductive interference. Modern well-designed machines are quite capable of attaining a satisfactory standard in these respects, but it is desirable for the shipbuilder to co-operate to this end and to see that all cable runs are arranged to transmit as little interference as possible. These points are discussed in fuller detail later in this paper, in the sections dealing with "motor design" and "cables."

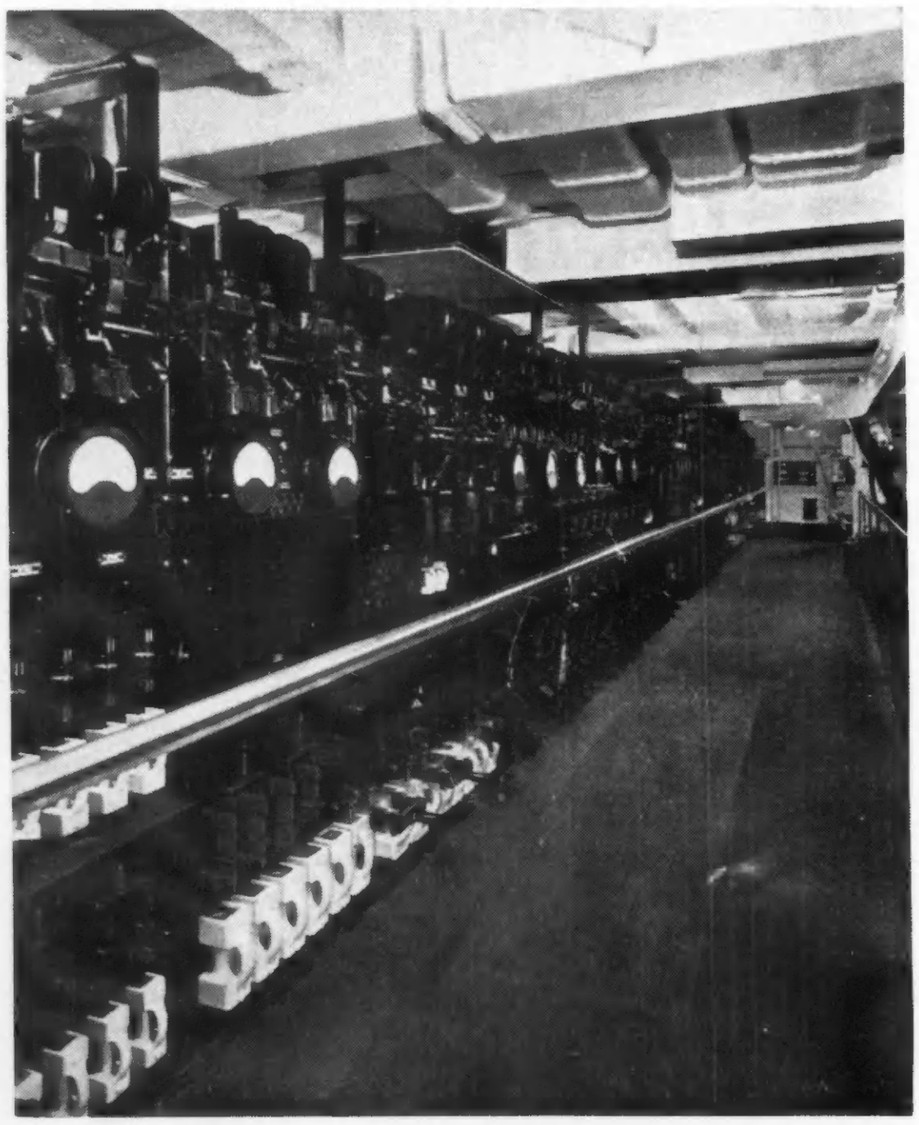


Fig. 4.—A main D.C. switchboard installed in the auxiliary engine room of a large liner.

The steering gear is usually of the electro-hydraulic or all-electric type (fig. 6), and on large ships the driving motors are usually arranged in pairs. Thus there is always one machine available for stand-by, although in close waters both machines may be and should be run together.

In addition to the above, a smaller machine run off the battery is sometimes installed. This can be arranged to start up automatically the instant the main steering-gear motors shut down, and its capacity is such that it will give steering facilities for a few minutes until the way is off the ship.

REFRIGERATION MACHINERY.

The problem of the control of refrigeration machinery is a very delicate one, and electrical operation offers many distinct advantages in this sphere. On some of the large cargo ships the refrigerating equipment is of particular interest on account of its size and of the fine degree of control which can be obtained.

The electrical installation may consist of, say, three 150-h.p. compressor drives together with brine and water circulating-pump motors and control gear. The compressors have to be run at full power before cargo is loaded, in order to cool down the cold-storage accommodation. During the voyage they are run at a very low speed to maintain the low temperature.

To meet these requirements a speed range (too great for shunt control) varying from 375 r.p.m. to practically zero is necessary. Series regulation has been used in the past, but the power dissipated in resistances is very considerable over a long voyage. An alternative arrangement, giving superior power economy for a greater speed range, is to employ a negative booster in series with the main motors, thus reducing the power otherwise wasted in heat. This method has been adopted with great success; speed control can be effected to the finest degree by varying the booster field. Consideration of price, weight, and space, may demand a single booster set capable of serving any of the three compressors. Moreover, the booster has to be cut in or out of any compressor-motor circuit without shutting down that machine and without varying the speed of any of the others. This is carried out by means of a change-over contactor panel common to all three motors and embodying an automatic starter for the booster set.

VENTILATION.

The ventilation of a ship presents one of the most fascinating and intricate problems with which

engineers have been called upon to deal. In addition to the natural difficulties arising from the maintenance of an equable temperature under climatic conditions varying from arctic to tropical (sometimes in a few hours), the whims of individual passengers have to be studied and catered for. The latter are met by a small cabin fan, which, if desired may be of the gyrating type whilst the general ventilation comprises pure air supplied by fans on deck through adjustable louvres and warmed as required.

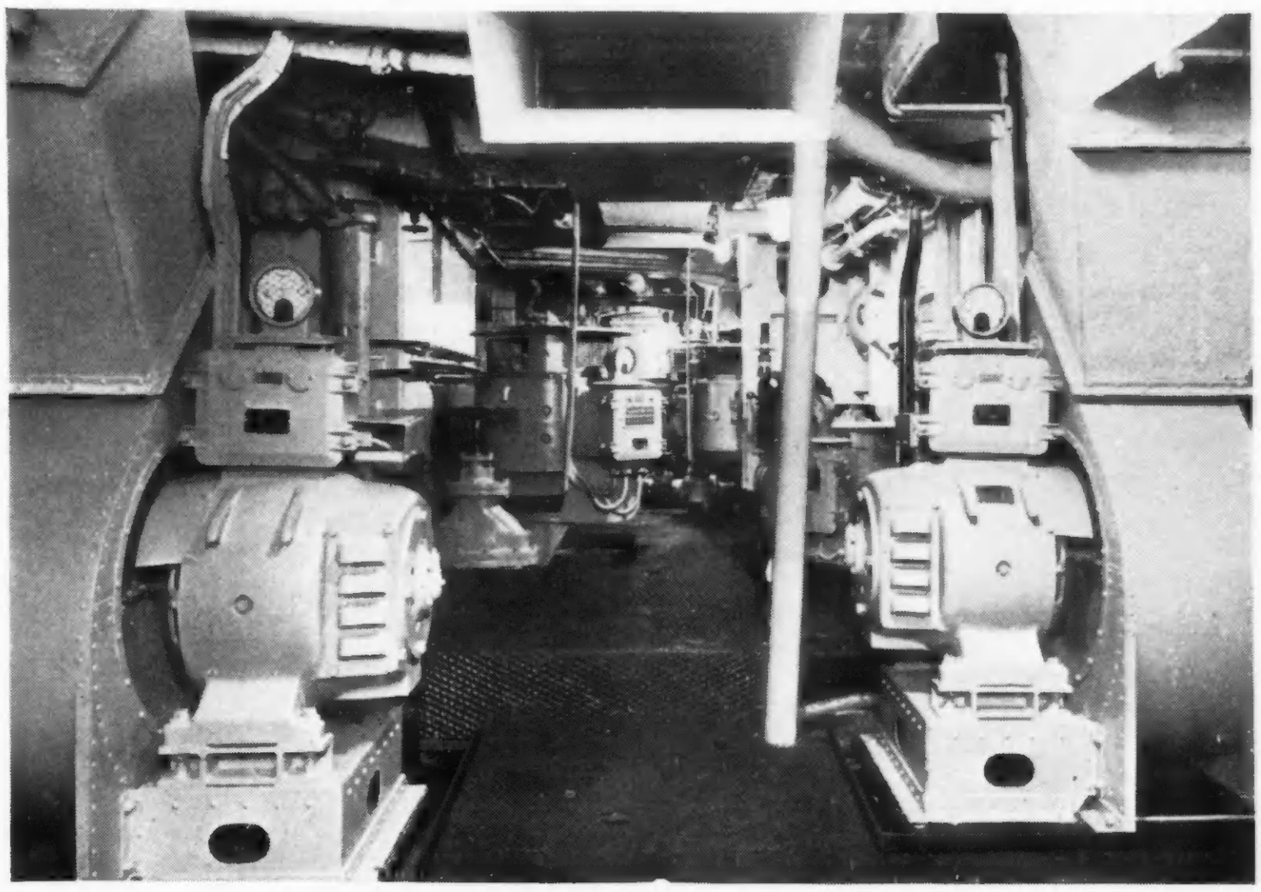


Fig. 5.—Motors with plural starter control units driving engine room auxiliaries.

DECK MACHINERY.

The deck machinery includes windlasses, capstans, winches, lifeboat and gangway hoists, etc. The use of electricity for deck auxiliaries is a comparatively modern development, coincident with the evolution of the Diesel-driven ship. The duties which such equipment is called upon to face are among the most arduous which could be required of any type of machinery. Deck auxiliaries are subjected to rapid changes of temperature, are sometimes totally immersed in sea water, and are liable to be damaged by falling or swinging weights. Great skill is therefore necessary in their design to enable them to carry out their duties. Their operation, particularly in the case of winches, is always in unskilled hands, and they must be capable of control to within very fine limits in order to avoid damage to personnel, cargo, and the ship itself.

Windlass.

The windlass is used to lift and house the anchor and to warp the ship. It must be capable of breaking the anchor out of the mud, raising it quickly, and housing it gently in the hawse pipe without damage to the bows of the ship. It therefore follows that during these operations, and when warping ship, a strong pull is required at low speeds. Ability to stall at any stage and to maintain this pull when stationary, and a quick "get-away" when hauling slack, are also essential.

Windlass and Capstan Control.

Contactors with drum control have proved satisfactory for large and medium powers. Creeping speeds can be arranged by means of either series resistance or an armature diverter, and these features, together with a magnetic brake of disc or solenoid type and a slipping clutch, ensure that the load is always well under control.

Constant-current control has similar advantages to contactor control, but special generators are required and full-load current has to be carried throughout the system while it is working; consequently the machines are correspondingly large.

Ward Leonard control is almost ideal for deck machinery, but the motor-generators in use with this system are both costly and bulky, and for this reason its use is somewhat restricted.

Booster control is a development of the Ward-Leonard system. It has most of its advantages and is far less costly since a motor of fairly high voltage can be used, the current being correspondingly low; on this system the motor-generator has only to develop a small voltage at full load and less than the line voltage at light loads. Thus the output of the motor-generator is of lower power than that of the Ward-Leonard set, allowing a much higher speed and consequently smaller frame size to be used. This system is now largely used for windlasses and capstans.

Briefly, the outfit consists of the main windlass or capstan motor supplied with current from the ship's auxiliary supply, and in series with the motor armature is the armature of the generator of a reversible booster set. The motor of the booster set obtains its supply direct from the ship's auxiliary supply. The main motor can therefore be supplied with a voltage which can be controlled from zero to nearly double the line voltage. By this means very fine control of the main motor can be obtained, and the whole arrangement is as nearly foolproof as is possible of attainment.

Cargo Winches.

In view of the importance of these auxiliaries (any trouble with the winch equipment may result in delay in unloading, with consequent deterioration of the cargo, and added expense on account of the ship itself being held up), it is essential that the electrical equipment associated with them should be

of the most robust character. The design should permit of easy and reliable control in the hands of unskilled operators.

Well-designed contactor gear fulfils these requirements, and its use is strongly advocated for cargo-winch working. The equipment consists of electrically operated contactors working in conjunction with a master controller; a reliable form of

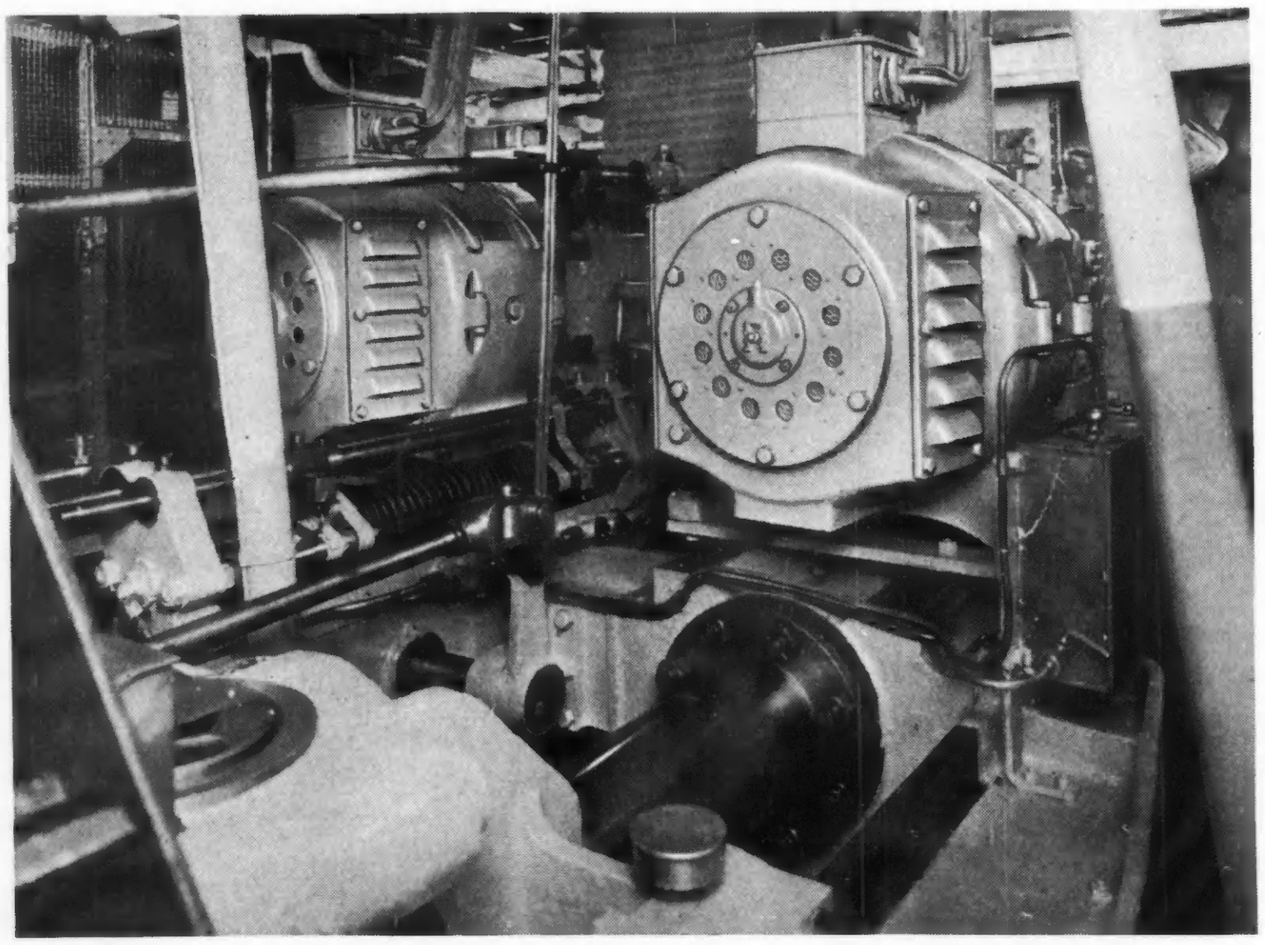


Fig. 6.—Steering gear driven by 42 h.p. motors.

time-delay device should be employed for controlling the acceleration of the contactors. Magnetic brakes of the disc or solenoid type, worked in conjunction with mechanically operated hand or foot brakes, are generally used to control the load whilst it is suspended. Dynamic braking has also been used with satisfactory results. Booster-controlled winches have given good service, but this form of control does not appear to have been used so extensively for winches as for windlass and capstan working, probably on account of expense.

It is suggested that wherever possible the electrical equipment of deck auxiliaries should be housed below deck or in deck houses. The greater efficiency of working in the latter case, due to the protection afforded the operator, will more than repay the extra cost involved; whilst in the case of capstans and windlasses there may be a great saving as ventilated gear may be used, with improvement in reliability owing to better overhaul facilities. In cases where it is impossible to protect the equipment it is necessary that it should be absolutely watertight and that its mechanical design should be of the most liberal nature. Even when the best of designs is employed, rapidly varying temperatures introduce the risk of condensation inside the machines and controllers, and breathing must be provided for.

It will be appreciated from the foregoing remarks that the insulation of deck machinery needs the most careful consideration. Mica and micanite are, in the authors' opinion, the best materials for this duty.

MOTOR STARTERS AND CONTROLLERS.

The importance of simplicity and reliability in the control of marine electrical equipment has for

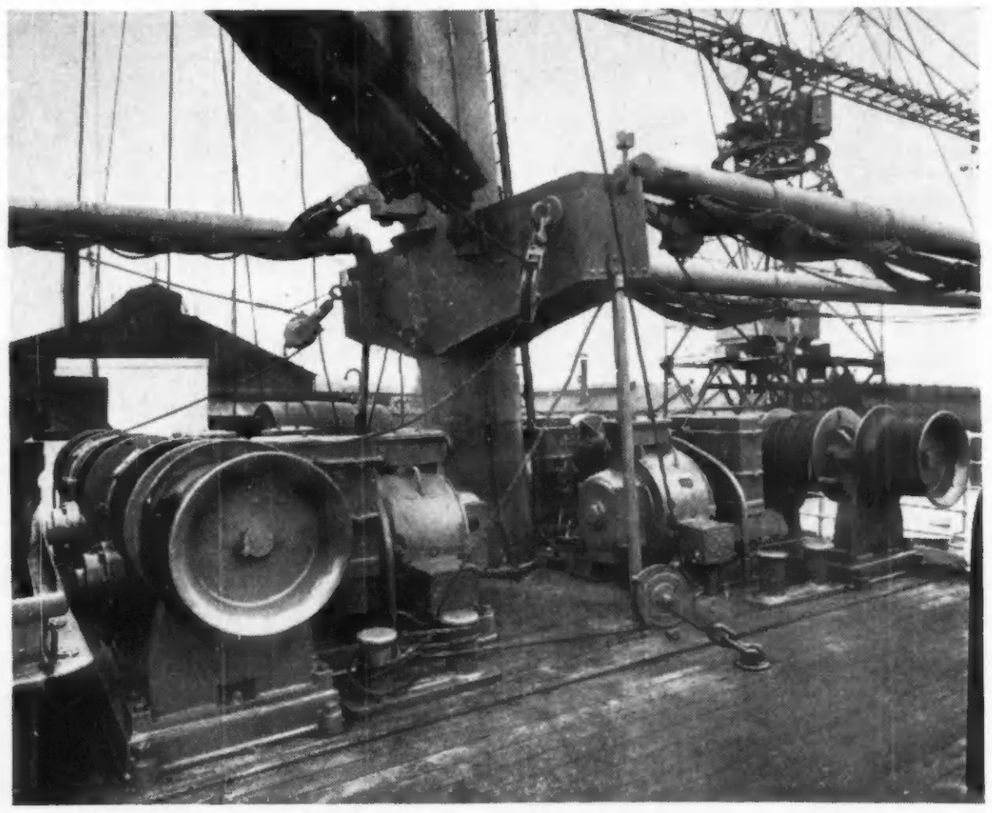


Fig. 7.—Deck winches driven by 24 h.p. motors.

many years engaged the attention of electrical engineers. It is essential that at all times the operator should be relieved of anxiety as to the rate of acceleration when starting motors, and thus misuse of the starter and the motor should be impossible. It is frequently desirable that a particular motor or group of motors should be capable of being started up, or having its speed controlled from a remote or

centralized position, and that indication shall be given that the machine is working satisfactorily.

For instance, it should be possible at all times for a spare steering-gear motor to be instantly started up from the bridge, or on a failure of the supply to the main busbars the emergency steering-gear motor should immediately come into operation automatically from the battery. A forced-draught fan, situated in a house on the boat deck, should have facilities for being started up and stopped from a position adjacent to the machine itself (to enable the engineer to ascertain that it is running properly), while starting and stopping and the speed should be controlled as required from the floor of the boiler

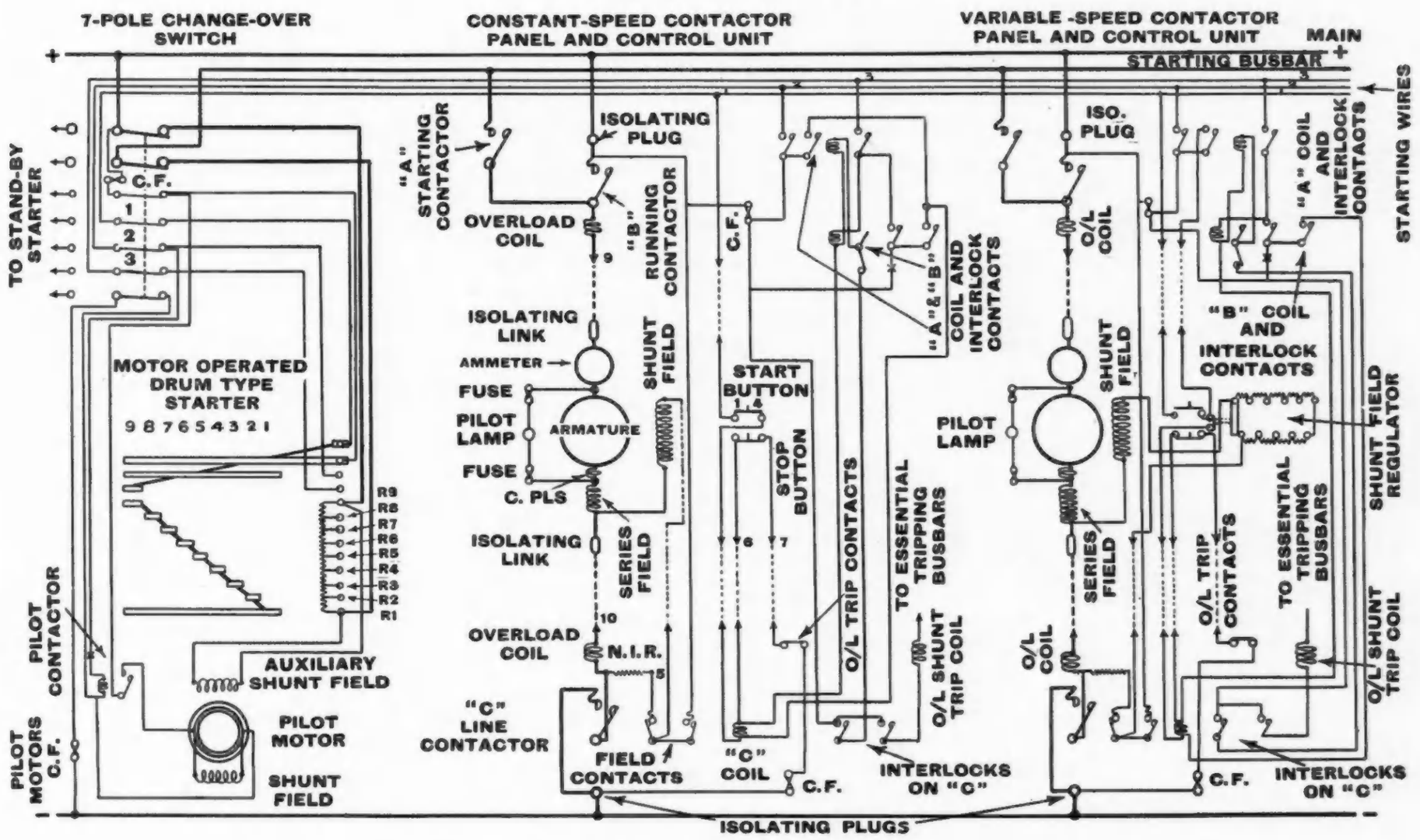


Fig. 8.—Schematic diagram of connections for plural starting equipment.

room. These requirements have led to the increasing use of automatic starters, and their use is advocated on every possible occasion. It is necessary that the time-delay device should be robust, reliable, and easily understood by the engineers responsible for its maintenance, so that repairs or replacements can be readily effected if necessary.

Many ingenious forms of time-delays have been developed, some operated by current control, others by the back e.m.f. of the motor itself, and yet others by mechanical means. While the first two types are largely used with satisfactory results they suffer from the disadvantage (particularly where remote control is used) that should the machine fail to complete its starting sequence the starter may remain in circuit, with resultant damage to the starting resistance and to the starter itself. Another disadvantage of some of these types is that when reciprocating machinery such as compressors, where the starting peaks fluctuate violently, is being started, there is a danger of the starter completing its sequence before the motor is up to speed. Air and oil dashpots are not recommended for marine use, as owing to variations in temperature between the tropics and colder zones they cannot be relied on to give a definite time-delay under all conditions.

Timing starters equipped with a clockwork timing device will accelerate a motor at a predetermined rate irrespective of load. The rate of acceleration is adjustable within a wide range according to the size of the motor. Should trouble such as a seized bearing or a jammed pump occur, the starter will progressively cut out the starting resistance until tripped by the overload relay, without damage to any of the equipment.

Automatic starters can be arranged for local and for remote control by means of push buttons, float switches, or pressure switches.

Limitations of space, particularly in engine rooms, have led to the development of a particularly interesting type of starter whereby one starter is made to serve a group of motors. The advantages of this type of starter, particularly for large engine rooms, will become apparent when consideration is given to the fact that a large number of auxiliaries are started up and run continuously throughout the voyage. In consequence the starter operates for a few seconds and then occupies valuable space, often for several weeks, without being used.

In one system which has been installed in a

number of large ships a group starting means known as a "plural starter" (figs. 8 and 9) is used for all engine room motors and refrigerating machines within a range of 5 h.p. to 50 h.p. approximately. Two starters and starting resistances are fitted at the back of the main switchboard and are coupled to a 2-way change-over switch. By means of this switch either starter can be instantly brought into use, and there is therefore a spare starter available for all machines at any time.

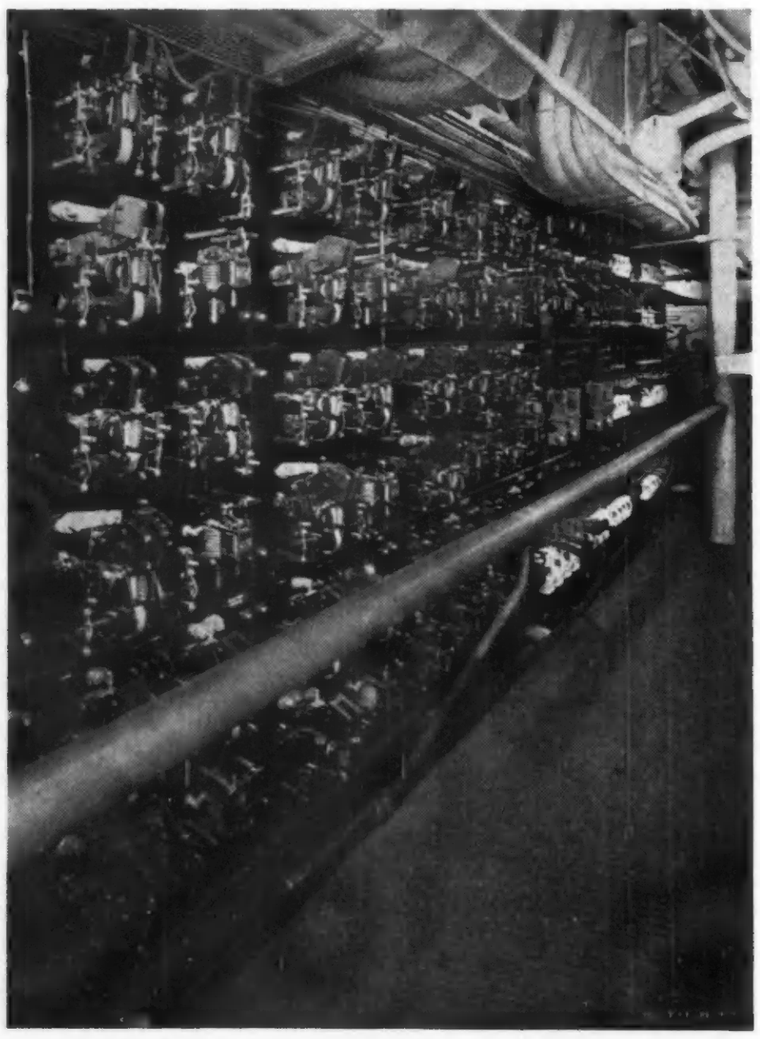


Fig. 9.—Plural-starter switchboard.

The starter consists of a motor-driven multi-contact drum controller, the driving motor being compound wound and having a separately excited field winding connected across part of the starting resistance. Consequently, with a heavy starting current there is a correspondingly heavy current through the field winding, and the speed of the controller motor is reduced. This results in a slow starting rate for a large machine and a more rapid rate of starting for a smaller machine.

Each machine on the plural starter has associated with it a contactor panel, and all these contactor panels are grouped together at the main switchboard. The active portion of the equipment is thus under the supervision of the switchboard electrician and is easily accessible for cleaning and maintenance.

Each contactor panel is equipped with positive and negative line contactors and a starting contactor, together with an adjustable overload relay. Mounted on each of the motors, in place of the usual terminal box, is a motor starting unit in a steel case with a door and inspection window, containing start and stop push-buttons, pilot running-light, and an ammeter. In the case of a variable-speed machine a shunt regulator with full field starting interlock is also provided.

Another form of control of this type, known as the "Uni-start" system, employs for the smaller motors a starter of the solenoid type, and the timing device consists of an eddy-current disc working between the poles of an electromagnet excited by the load current. For starting the larger motors a contactor-type starter is used, the individual contactors which progressively cut out the starting resistance being controlled by an eddy-current timing device similar to that employed for starting the smaller machines.

MOTOR DESIGN.

There are certain drives, such as for deck machinery, forced-draught fans, etc., for which the use of totally enclosed (fig. 11) or pipe-ventilated machines is preferable or at times essential. With the exception of these instances, enclosed ventilated machines, protected against dripping moisture, have proved quite satisfactory (fig. 10). In order to ensure continuous reliability, however, it is necessary that the motors should have large openings with easily removable covers to permit of ready inspection of the machine and easy accessibility for cleaning purposes. It is also necessary that the operating personnel should make use of these facilities, as in the authors' experience a very large proportion of such electrical troubles as have occurred with motors and generators owe their origin to the presence of accumulated dirt and oil.

Ball and roller bearings are being used in increasing numbers and their use is advocated wherever possible, provided the design of the housing is sufficiently accessible to permit of easy inspection and removal. The housing should also be sufficiently robust in construction to prevent distortion, and it must be capable of efficiently retaining the grease. Self-aligning bearings if well designed tend to eliminate much of the trouble which can be experienced due to errors of assembly and alignment.

There are certain machines such as ventilating units and others, situated in close proximity to the bridge or to passenger accommodation, for which the maximum attainable degree of silence is essential. Noises may originate from two sources, mechanical and magnetic.

The main causes of mechanical noises are (1) bearings, (2) windage, and (3) brush chatter. Journal bearings are undoubtedly quieter in service than roller or ball bearings and it is desirable to use journal bearings where a special degree of silence is necessary. Well-designed ventilating ducts and fans will eliminate as nearly as practicable noises due to windage, and provided the brush gear is of robust construction and the commutator maintained in

reasonable condition no trouble should arise through brush noises.

In d.c. machines, noise of magnetic origin is usually most troublesome as the noise is often of a penetrating nature and may vary in pitch and degree with any change in load or speed of the machine. It is not proposed to enter into details regarding the design of super-silent machines, beyond referring to the fact that the chief source of magnetic hum is variation of flux density in the air-gap due to changing reluctance in the magnetic circuit as the armature teeth pass under the poles. Noise due to this cause can be reduced to a minimum if the armature slots are skewed relatively to the axis of the shaft, or alternatively by skewing the poles or pole shoes. Carefully-chamfered pole-shoes also help to reduce noise by minimizing any disturbance caused by the teeth entering or leaving the pole face.

From the foregoing it will be seen that ordinary commercial standards of silence are not suitable in the case of machines in proximity to the bridge or to passenger accommodation. Super-silent machines should always be specified for these duties.

HOTEL LOAD.

A modern liner is really a large floating hotel, and when at sea the travelling public demand a standard of comfort as high as or even higher than that obtaining in the best hotels ashore. The shipowner, therefore, in his effort to attract the travelling public to his ship, has concentrated upon electricity to provide every known means of comfort and safety. Consequently the most modern types of lighting, heating, and cooking, equipment are installed. Telephones and lifts are provided for every possible occasion, and illuminated signs and signalling systems have been developed which are the last word in efficiency.

Apart from questions of safety and speed, a ship's reputation may be made or marred by the quality of its cuisine, and electricity offers unrivalled facilities in this sphere (fig. 12).

The magnitude of a modern galley installation will be made manifest when it is pointed out that the maximum galley load may be between 600 and 700 kW.

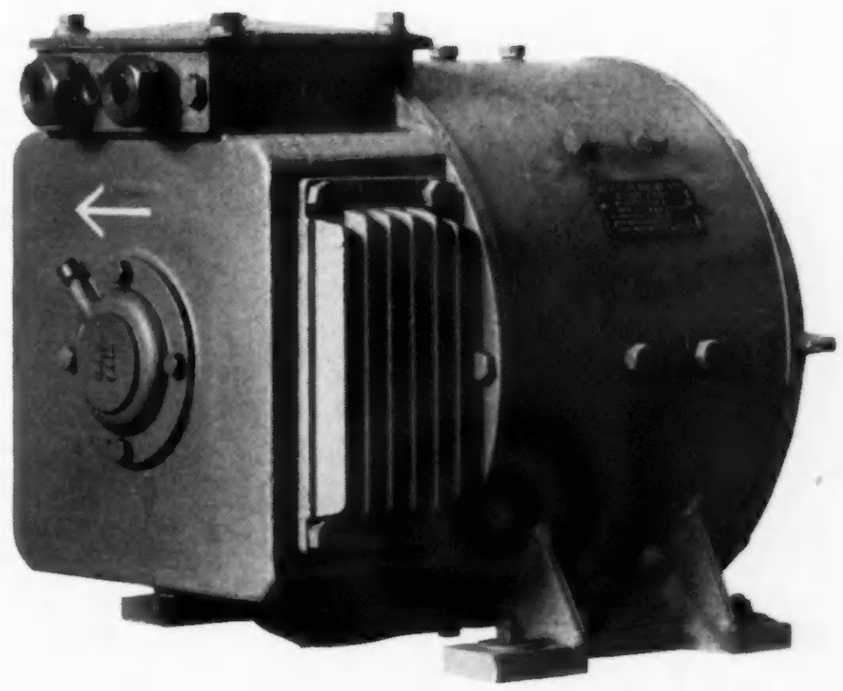


Fig. 11.—Standard marine motor.

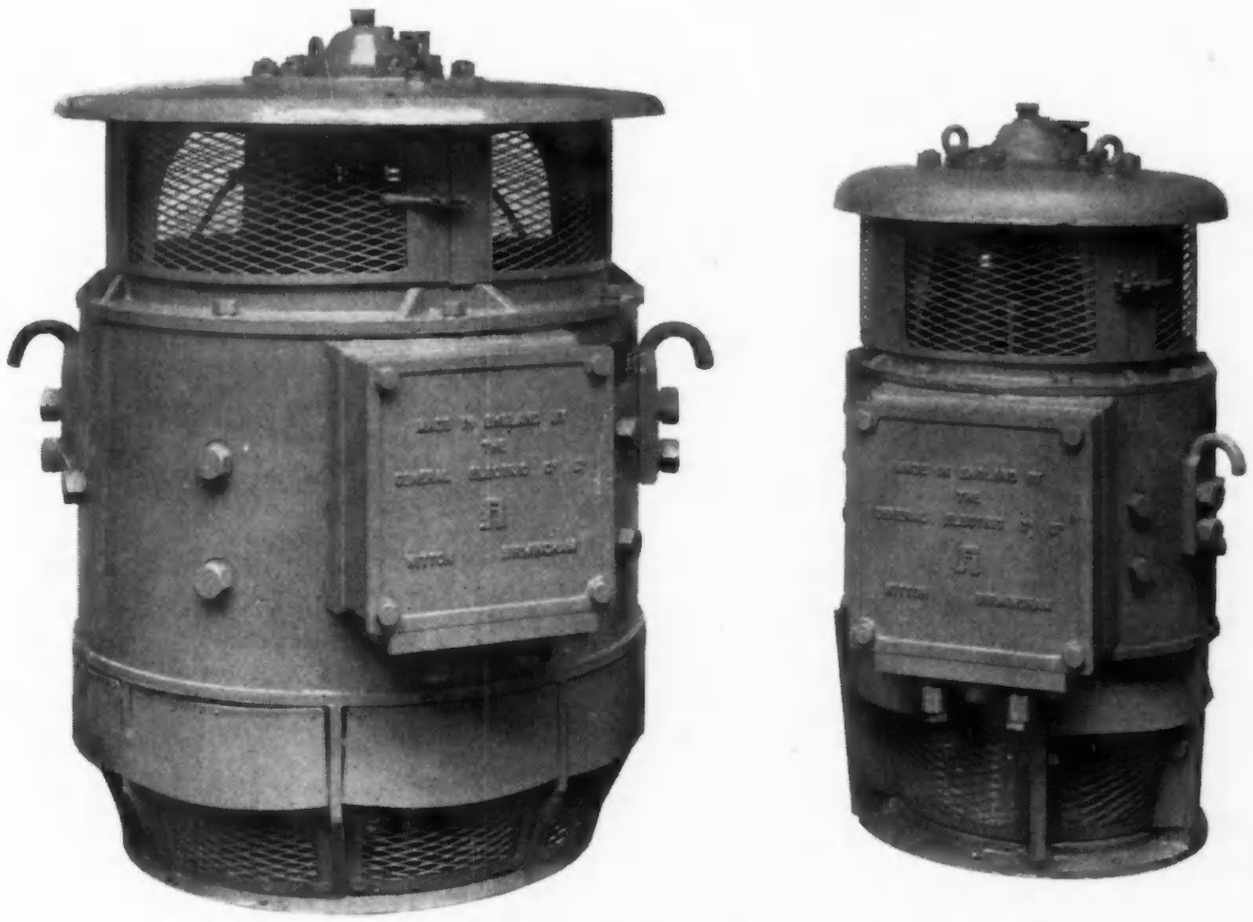


Fig. 10.—Two typical vertical spindle marine motors.

CABLES.

The importance of the cables on a ship cannot be stressed too much; the cables are the only link about which there may be doubts as to whether it will stand up to the demands made during the 25 year's service which is expected of the ship and of all the gear in it.

There has been considerable difference of opinion regarding the use of pure rubber next to the copper strand. In this connection, the Admiralty has had considerable experience, from which the merchant service would be wise to benefit. Single-conductor cable should be avoided, and 3/.029 in. should be the smallest size used. This ensures greater flexibility than would be the case if an equivalent single conductor were used, and the cable is less liable to fracture when bending.

Lead-covered cables should be braided in order to protect the lead when the cable is being pulled through bulkheads, etc., and all cables should be fire-resisting compounded overall as a precaution against the spreading of fire along the braiding. This protection may take the form of a white-lead com-

pounding. Where subject to mechanical damage the cable should be armoured and again braided and fire-resisting compounded.

There is no doubt that the question of cable-runs in a ship should be given more and earlier consideration than has been devoted to it in the past. It is becoming recognized that, with the increasing use of electricity on board ship, particularly for propulsion, the lay-out of the cable-runs needs even more care than that of the pipe-runs. The latter, especially in a passenger vessel, present a big problem, and the cable-runs are often even more complicated. If correct and just consideration is given to these points, and if the best of cables are used, shipowners can rest assured that the life of their cables will equal the life of the ship.

MISCELLANEOUS EQUIPMENT.

There is probably no more concentrated application of electricity than in a passenger liner of, say, the following dimensions: 550 ft. long, 75 ft. beam, 100 ft. (approx.) depth. The following is a list of equipment, apart from machinery, installed in the "Queen of Bermuda," a modern liner of approximately the above dimensions and carrying 800 passengers.

Galley Equipment.—This includes 2 8-oven island ranges; 20 hot cupboards; 1 fish fryer; 2 baking ovens; salamanders, hot-plates, and carving tables; 10 electric water boilers and urns.

Miscellaneous.—One 450-line telephone board; 250 electric signs and indicators; 2,250 bell pushes; 400 electric radiators; 400 electric towel rails; 650 electric fans for cabins; 410 miles of conductors in cables and wires; 5,000 fuse units; 6,000 switches and control units; 5,000 lighting fittings; 20,000 electric lamps.

It is interesting to note that the efforts that have been made towards standardization of accessories in recent years have been so successful that 80 different patterns will cover the whole of the lighting fittings for cabins, all utility deck fittings, fuses, fans, switches, plugs and sockets, lampholders, heaters, bells, fire alarms, and telephones. The design of each of these fittings has to be studied from the point of view of corrosion, water-tightness, and rough usage, and each one of them presents a special problem when compared with the standards that are used for shore working. In very few cases are the accessories normally used ashore suitable for shipboard use.

(To be continued).

Fig. 12.—View in the galley of a modern liner showing two island electric oven ranges.

An Electrical Test Recorder

By G. CHELIOTI,
Works Manager, Osram-G.E.C. Lamp Works.

The subject of this article may be called in general terms a device for supervising and recording the continuance or discontinuance of a number of separate events, and it is believed that it embodies a number of original features. It will become clear in the course of the description that the device could be applied to a very wide range of uses; thus, though when employed for the purpose for which it was primarily designed it supervises separately the continued burning of each of a number of electric incandescent lamps which are under test and provides a permanent record of their individual lives to destruction, it could equally well be used for so widely different a purpose as the recording of the continuous or discontinuous operation of a number of machines in a factory. It will, however, be convenient to deal with the subject mainly in relation to the immediate purpose of the design.*

THE maker of incandescent electric lamps is obliged, in order to control the quality of his product, to make a large number of tests to destruction of individual samples, and if he does so on as large a scale as he should in order to obtain the maximum benefit, he will find that the requisite expert supervision and the large consumption of electrical energy amount to quite a serious charge. Fortunately, however, it is well-known that with remarkably little sacrifice of accuracy such tests can be greatly accelerated by overloading the lamps, within certain limitations which are too technical to be discussed here, so that, for example, the life history of a batch of lamps which would normally average 1,200 hours burning, may be compressed within a hundredth of that time. The large scale adoption of this type of testing in the Osram-G.E.C. Works some years ago disclosed certain difficulties, particularly that as the "magnification," as it were, is a hundred to one, it is necessary to note rather precisely the moment at which each of a batch of lamps under test burns out, and unless continuous supervision is provided day and night, or at least throughout whatever hours tests are allowed to run, intolerably large errors will arise. Moreover, though it seems easy enough to look along a row of lamps periodically and to note each casualty, as the gaps in the ranks increase—of course they do so irregularly—it actually becomes more and more difficult to maintain accurate control. Human frailty, also, is a factor, as such work is extraordinarily monotonous and it is practically impossible to check the records, so that it tends to be done somewhat loosely. It was evident that a "robot" was needed which would relieve flesh and blood of this dreary task and would provide a permanent record of unimpeachable accuracy.

Two outstanding requirements were, first, it must be robust enough to stand up to constant test room work: an arrangement which would be satisfactory for a short time with expert care under laboratory conditions would not suffice. Secondly, as lamp testing is always a delicate and exact task which can be carried out only in strictly controlled conditions, the method used must introduce the least possible disturbance to the lamps or in the circuits associated with them. Hence the design must be mechanically complete in itself and not dependent for its operation on energy derived from the test circuits, from which only the feeblest possible "signals" should be tapped. It is true that this last condition, though imposed by the particular requirements of lamp testing, would not necessarily exist in other possible applications, but in any case the design of the electrical side of the recorder is greatly helped when only very feeble electrical impulses have to be received.

The first point to settle was the frequency of supervision; in full length life testing of lamps it is customary to make checks about once every twelve hours, so that on the hundred to one ratio, about 0.12 of an hour was indicated, and in practice the simpler fraction of 0.1 hour, or six minutes, was adopted. The event to be recorded was the continued burning of each lamp, and it was thought that the well-known method of pricking a chart would be very suitable for a periodical supervision of this kind. Another principle which suggested itself was that the recording mechanism should operate continuously *unless restrained*, this restraint to be *normally* imposed and to be withdrawn during the continuance of the event to be recorded—in this case the burning of a lamp. There would then be no limit upon the weight and robustness of the moving parts or upon the amount of power used to drive them, while the actual supervisory signal need be made to perform only the relatively light duty of controlling a "hit-or-miss" device. Also, for the sake of reliability, it was desirable that the burning of a lamp on test

* The Test Recorder is protected by Patent No. 6249/32.

(or any other event being recorded) should give a positive indication during continuance and give no further signal on cessation, the reverse arrangement leaving too many loopholes for error. In order that the lamps should be separately "watched," it was necessary to provide means to transfer the "attention" of the machine from one to the other, the obvious method being a radial switch arm moving over a large number of peripheral contacts, with means for synchronising the recording mechanism so that every movement of the pricking needle should be associated with a particular contact and through it with a particular lamp. Finally, the individual lamps must be made in some way to signal to the recorder whether or not they continue to burn, and for this purpose the available choice of method was almost embarrassing. It has already been remarked that the energy of the signals should be small, and the obvious possibility of using photoelectric cells was very tempting, as this would leave the lamp circuits entirely undisturbed, merely making use of a minute fraction of the radiant energy which in any case runs so prodigally to waste during lamp life tests. The project was, however, regretfully abandoned, as it seemed necessary to provide a separate cell to watch over every lamp or else to add a complex mechanism whereby a single cell could be made to "scan" several or all of the lamps in succession. Either way, of course, would be perfectly practicable, but much expense would be involved, as well as risk, in the second case at least, of mechanical derangement. Alternatively, it would evidently have been possible to use a relay or transformer* in series with each lamp, but no suitable standard unit of sufficient sensitivity appeared to be available, so a thermostatic switch, on the lines of those used in automatic flashing devices for advertising, was considered. There were, however, objections which need not be discussed in detail, and the eventual choice was a very low series resistance, the fractional voltage drop across this resistance being impressed on the control grid in an amplifying valve circuit.

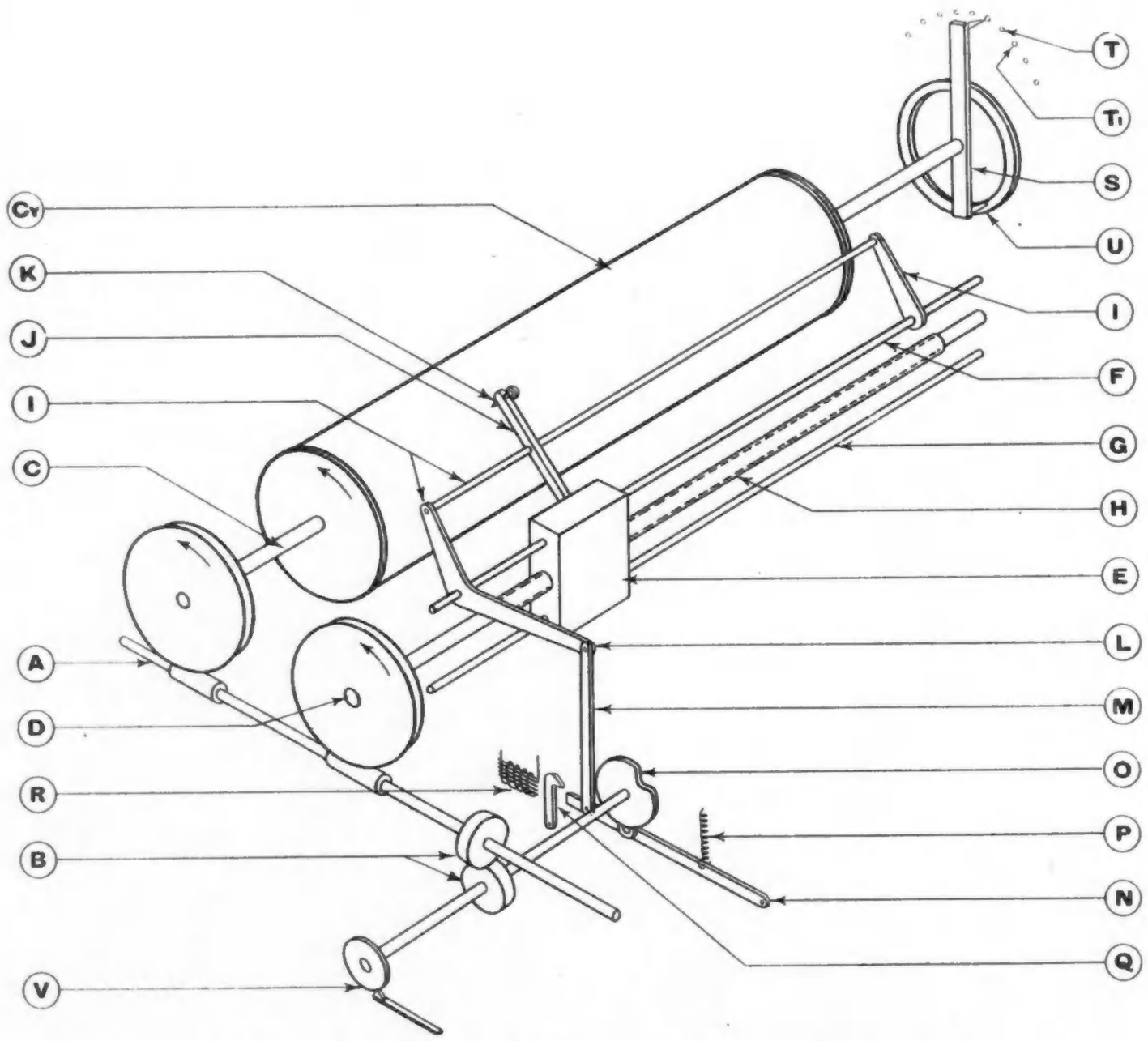


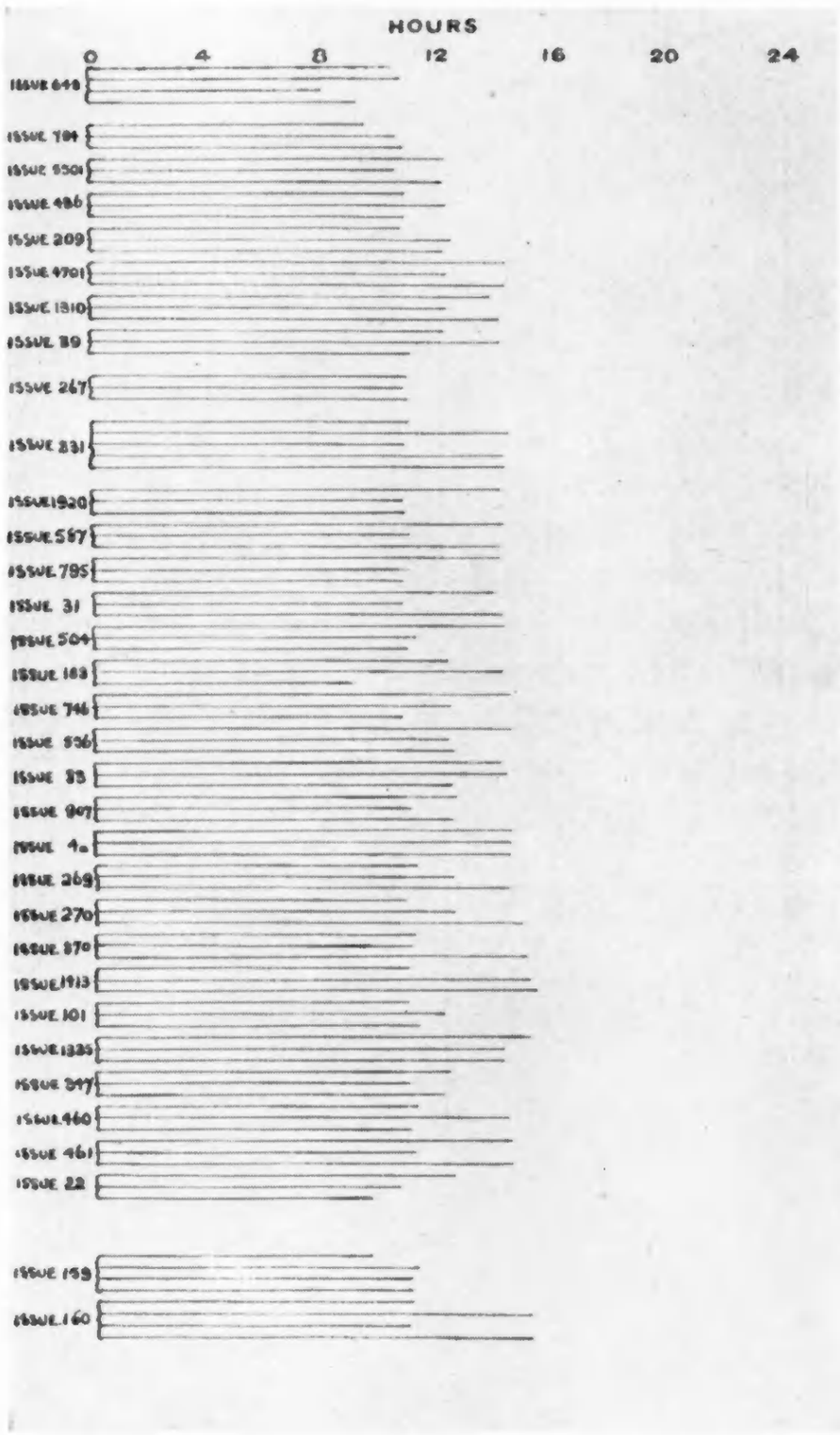
Fig. 1.—Diagram illustrating chart-marking mechanism.

The design now began to take form. The record of the life of each lamp would most conveniently consist of a straight line of perforations pricked by the needle, each one marking off an interval of six minutes, and such a series of records would be produced on the surface of a cylinder if the latter rotated in synchronism with the selector switch and if the pricking needle, without angular movement, travelled parallel to the axis of the cylinder in proportion to time. The conventional diagram in

* Transformers have actually been used since in testing lamps of high current consumption.

fig. 1 should now enable the reader to follow a more detailed description.

A synchronous motor at 1,500 r.p.m. drives the main shaft A of the recording machine, through a reduction gear, at 20 r.p.m. The chart cylinder Cy, set at right angles to the main shaft, is driven through a worm gear giving a reduction of 120 to 1, and therefore revolves once in six minutes. A 40 t.p.i. feed screw H, parallel with the axis of the cylinder and driven at the same speed by a similar gear, drives the "pricker" carriage E at 0.25″ per hour, covering the twelve inches effective length of cylinder in 48 hours. A third transverse shaft, driven through a 1:1 skew gear B, carries two cams operating respectively the pricker K and a contact breaker V, of which the purpose will appear presently.



As it was desired to record tests of up to at least 100 lamps simultaneously, the chart adopted was ruled with 120 parallel lines spaced 0.1″ apart, giving a total width of 12″, and the cylinder was accordingly made with a circumference of 12″, allowing for the thickness of the chart paper. The ruled lines therefore lie on the cylinder surface 3° apart and its revolution brings them successively under the pricker at 3 seconds intervals. (In practice standard 1/10″ squared paper is used, the transverse rulings representing the time scale at 1″ = 4 hours.) The pricker carriage, sliding on guide rods F and G, is driven by a split nut engaging the feed screw, and

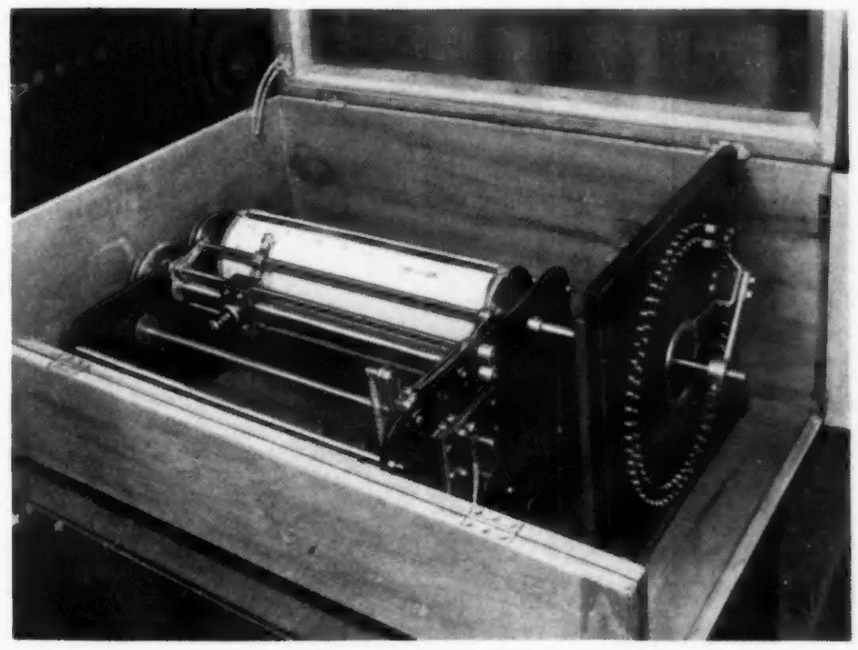


Fig. 3.—Top view of recorder with casing opened to show chart cylinder, selector switch and mechanical details.

an arm J, flexibly attached to the carriage, is fitted with a gramophone needle which presents its point vertically to the cylinder surface and is normally suspended about 0.2″ above it. A slot in this pricker arm loosely embraces a rod I fixed at either end to radial arms rocking on an axis F, parallel to the feed screw. The pricker arm therefore moves freely, with its carriage, parallel with the chart cylinder, but when the rocking bar operates, the pricker arm is impelled towards the cylinder and the needle point forced

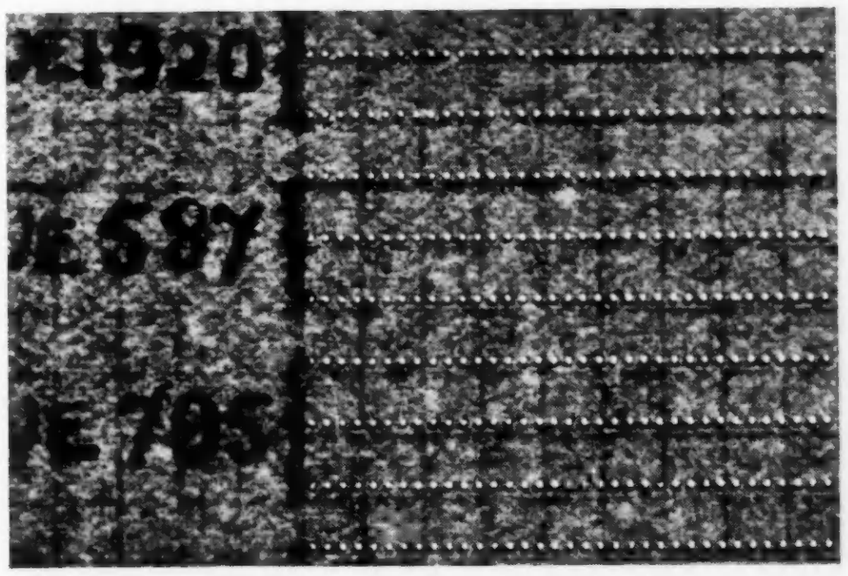


Fig. 2.—Typical test chart. Lines have been ruled over the perforations in the illustration on the left in order to make the perforations plain. On the right is an untouched and magnified illustration of part of the chart.

into the surface of the chart. The rocking bar is spring loaded, and would keep the needle permanently pressed against the chart were it not for the controlling action of the cam O already mentioned, which normally holds it in the "off"

position but once in each revolution allows it to advance and then immediately withdraws it. It will be remembered that the cam shaft revolves once in 3 seconds, so that without some further control the pricker would operate continuously, producing a symmetrical pattern of impressions on the chart, spaced 1/10″ apart around the circumference of the cylinder and 1/40″ apart parallel to its axis.

We come now to the actual linkage between the machine and the lamps undergoing test. The rocking bar, besides being controlled by the uniformly revolving cam, is further restrained by a "hit-or-miss" catch Q which in turn is operated by an electro-magnet R governed by signals received from the lamps under test. These signals are picked up by a radial selector arm S mounted on the cylinder shaft and rotating with it. The arm carries a contact finger wiping over the surfaces of 120 studs (T, T1, etc.) spaced 3° apart, the passage from stud to stud therefore being at the same rate as the operation of the pricker—once every 3 seconds. The signal picked up from a live stud—*i.e.*, one connected to the pilot wire from a circuit on which a lamp is still burning—consists of a potential difference to earth

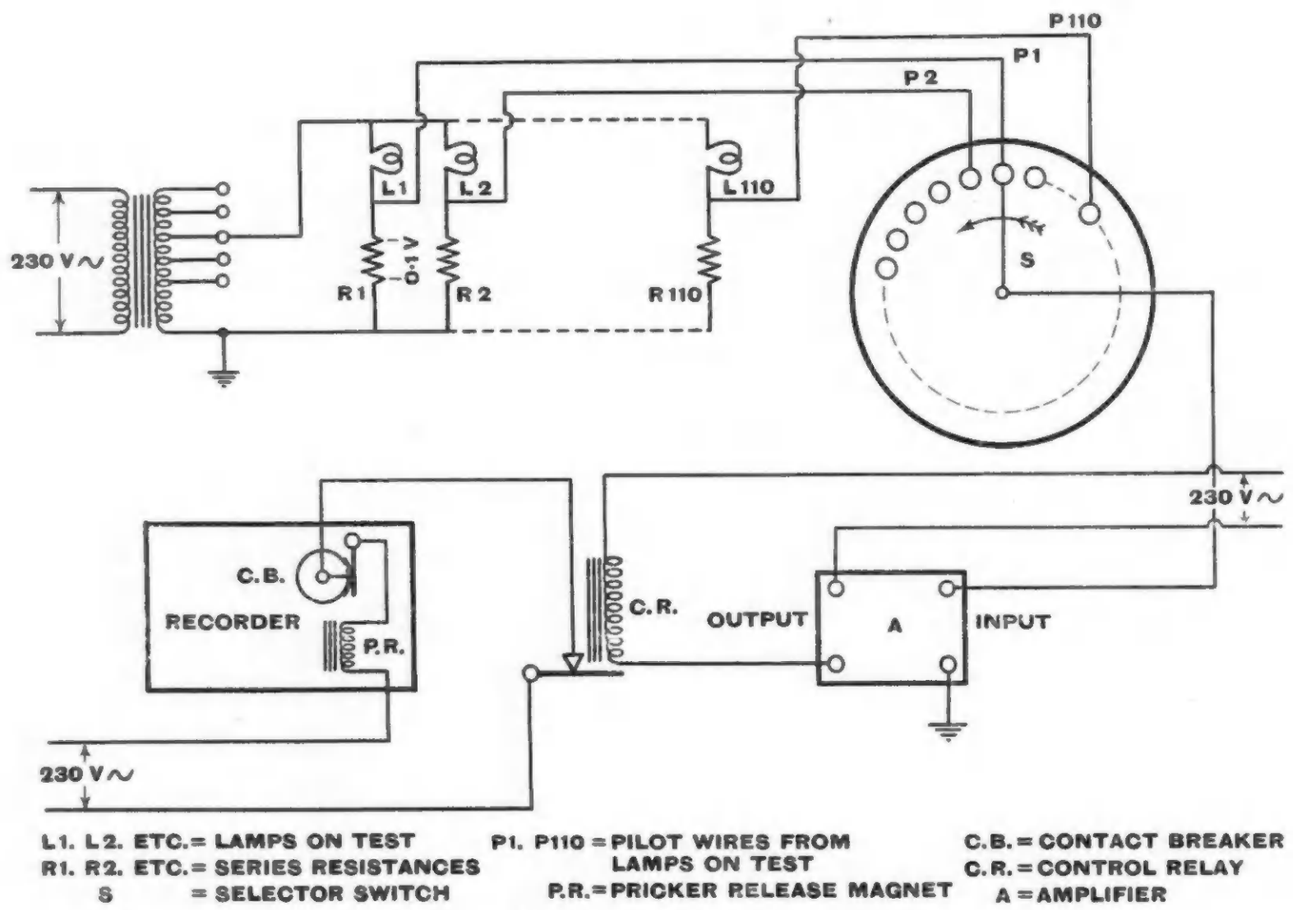


Fig. 4.—Diagram of connections.

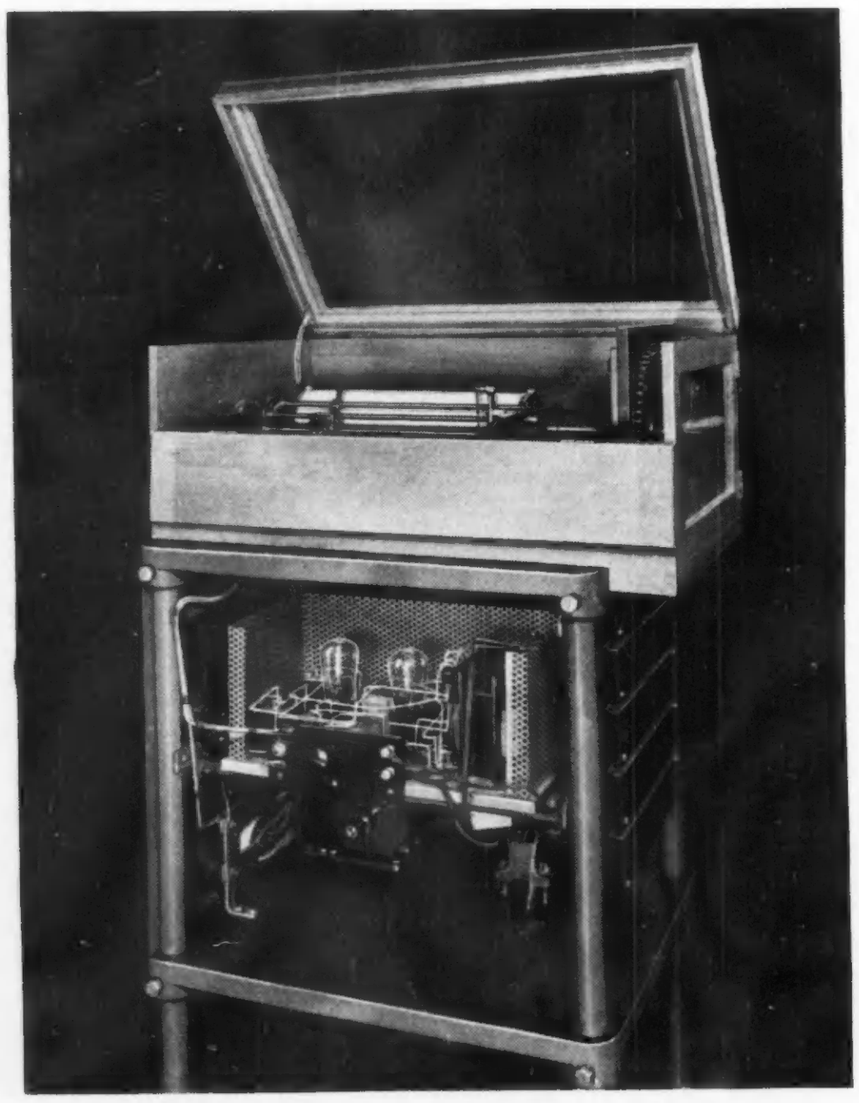


Fig. 5.—General view of recorder with front casing removed to show amplifying unit.

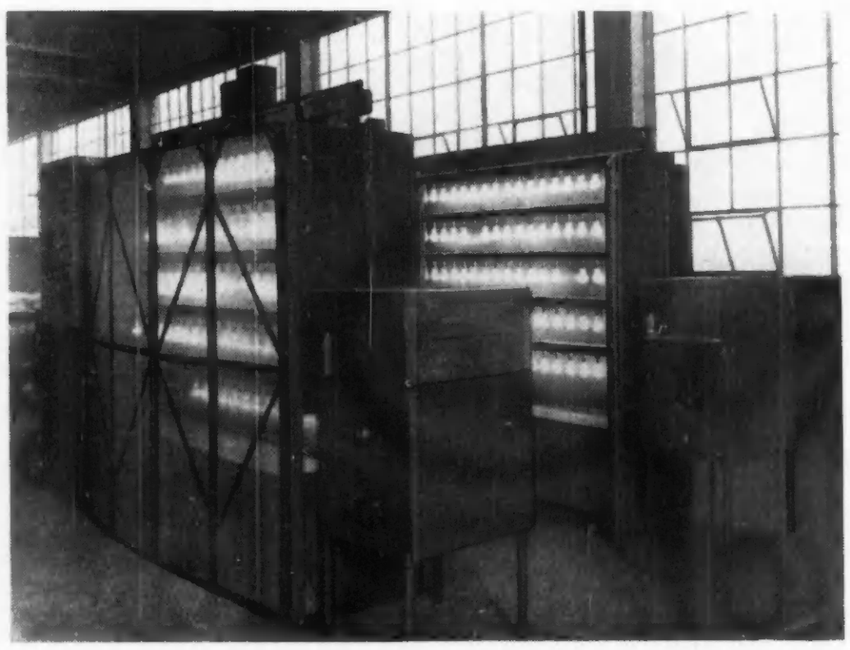


Fig. 6.—Two recorders working on lamp life test racks.

of 0.1 volt. The selector arm passes this signal to the collector ring U connected to the input terminals of an amplifying circuit (see fig. 4), the output being led to a sensitive relay which, when energised, closes a

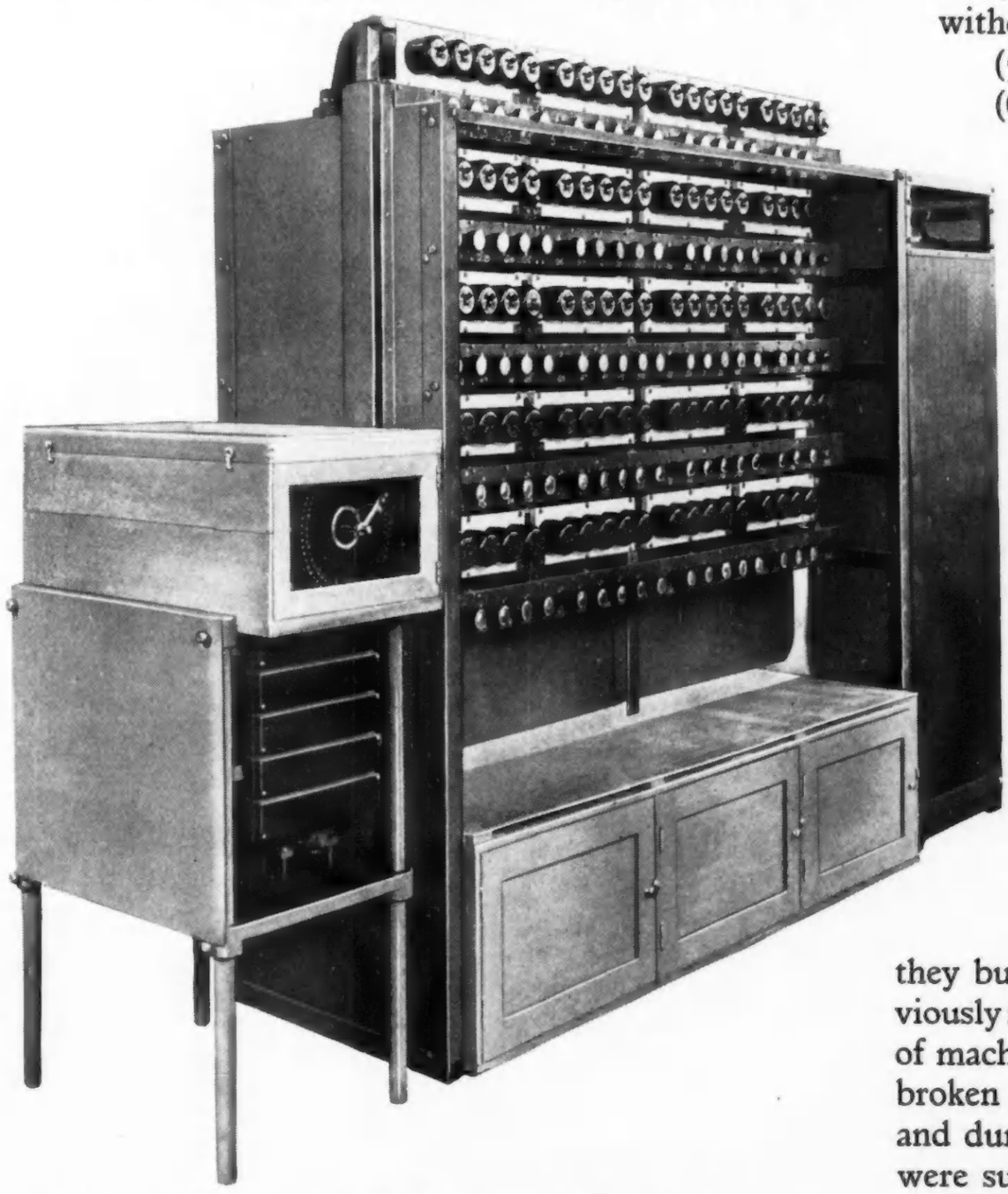


Fig. 7.—Reverse view of one recorder and lamp life test rack. Note the individual circuit breakers for each lamp.

pair of contacts in series with the electro-magnet R controlling the "hit-or-miss" release. As the relay is a rather delicate piece of apparatus, it was thought advisable to relieve it of the duty of actually making and breaking the fairly heavy current needed to operate the release, so a suitably timed cam-operated contact breaker, designed somewhat on the lines of a magneto breaker, and fitted with tungsten contacts, was added in series. This circuit is connected direct to the 230 volts A.C. supply.

It is hoped that this description has made clear the general manner of working, the exact sequence of events (in the case of a still burning lamp or, in any other application, if a positive signal is received from the selector) being :—

(1) Selector finger contacts with stud.

(2) Relay is immediately energised through A, closing pilot contacts.

(3) Cam-operated contact breaker closes.

(4) Electro-magnet is immediately energised, withdrawing detaining catch.

(5) Cam releases rocker bar.

(6) Rocker bar operates pricker.

(7) Cam withdraws rocker bar.

(8) Contact breaker opens.

(9) Electro-magnet is immediately de-energised, allowing detaining catch to return to "on" position.

(10) Selector finger leaves stud.

(11) Relay is immediately de-energised, opening pilot contacts.

If no signal is received, events (2), (4), (6), (9) and (11) do not occur and the chart is not marked. As the needle marks once every 6 minutes for each lamp so long as it burns, the impressions build up into continuous parallel lines of perforations, of which the varying lengths at the end of the test are proportionate to the lives of individual lamps. In this particular application each of the lines is normally continuous between its beginning and end, as the lamps are not normally switched off at all until they burn out, but if the machine were used, as previously suggested, for checking the operation of a group of machines in a factory, the lines would naturally be broken up into lengths depending on the number and duration of interruptions to which the machines were subjected. For pure testing work, however, it is almost impossible to imagine any kind of electrical or mechanical device under test which could not be made, by quite simple means, to signal its continued operation to a recorder of this kind, and it is possible in the same mechanism to embody auxiliary devices which will actually control operations in the test procedure itself. For example, it has already been used for tests in which it is necessary for the load to be periodically switched on and off, and auxiliary contacts on the selector arm have been made to control this function through suitable contactors.

The experimental machine shown in the illustrations, and several later models, were made by the Union Works of The General Electric Company, Ltd. The author desires to acknowledge with thanks much assistance received both from the Union Works and from several of his own colleagues in the working out of the details of the design and in the overcoming of the initial difficulties.

The Electrification of an Indian Tobacco Factory.

By P. S. JACKSON, M.I.E.E.,
Chief Engineer of The General Electric Co. (India) Ltd.

THE Calcutta factory of Carreras (India), Limited, was completed in March, 1933. Modelled on the lines of the parent factory in London, it is described in the official report of the Senior Inspector of Factories in Bengal as "having no equal in Bengal and probably no superior in India." Originally, the building was a tea warehouse of the Calcutta Port Commissioners. In constructing the new factory the shell of the old building was used in order to save time and it is worth recording that within three months the whole of the extensive alterations involved was completed and the new plant installed. This work was carried out to the designs and supervision of Mr. W. H. Louden, Director and Chief Engineer of Carreras Ltd., London, and Mr. M. C. Taylor, Chairman and Managing Director of Carreras (India) Ltd.

The plant installed is of a particularly interesting character and embodies many novel features. For power and lighting purposes electricity has been used throughout, the contract for the whole of the electrification involving E.H.T. and L.T. switchgear, transformers, power and lighting, wiring work and all motors and control gear being entrusted to The General Electric Co., Ltd.

The manufacture of tobacco and cigarettes from the raw material is of sufficient interest to warrant more than a mere reference, and it is therefore proposed to describe the new factory and to outline the various processes employed before dealing with the electrical equipment installed.

The factory itself, fig. 1, is 90ft. high and comprises four floors each having an area of 22,600 square feet. The front of the building on the first floor contains administrative and general offices equipped throughout with electric ceiling fans and lighting fittings. The factory proper is lit by means of 110 "Biflector" fittings with 300 watt Osram bowl sprayed gas-filled lamps. The ground floor is occupied by actual manufacture, the first floor chiefly by packing, the second floor is utilised as a store-room, while the third floor houses lift operating mechanism and water storage tanks.

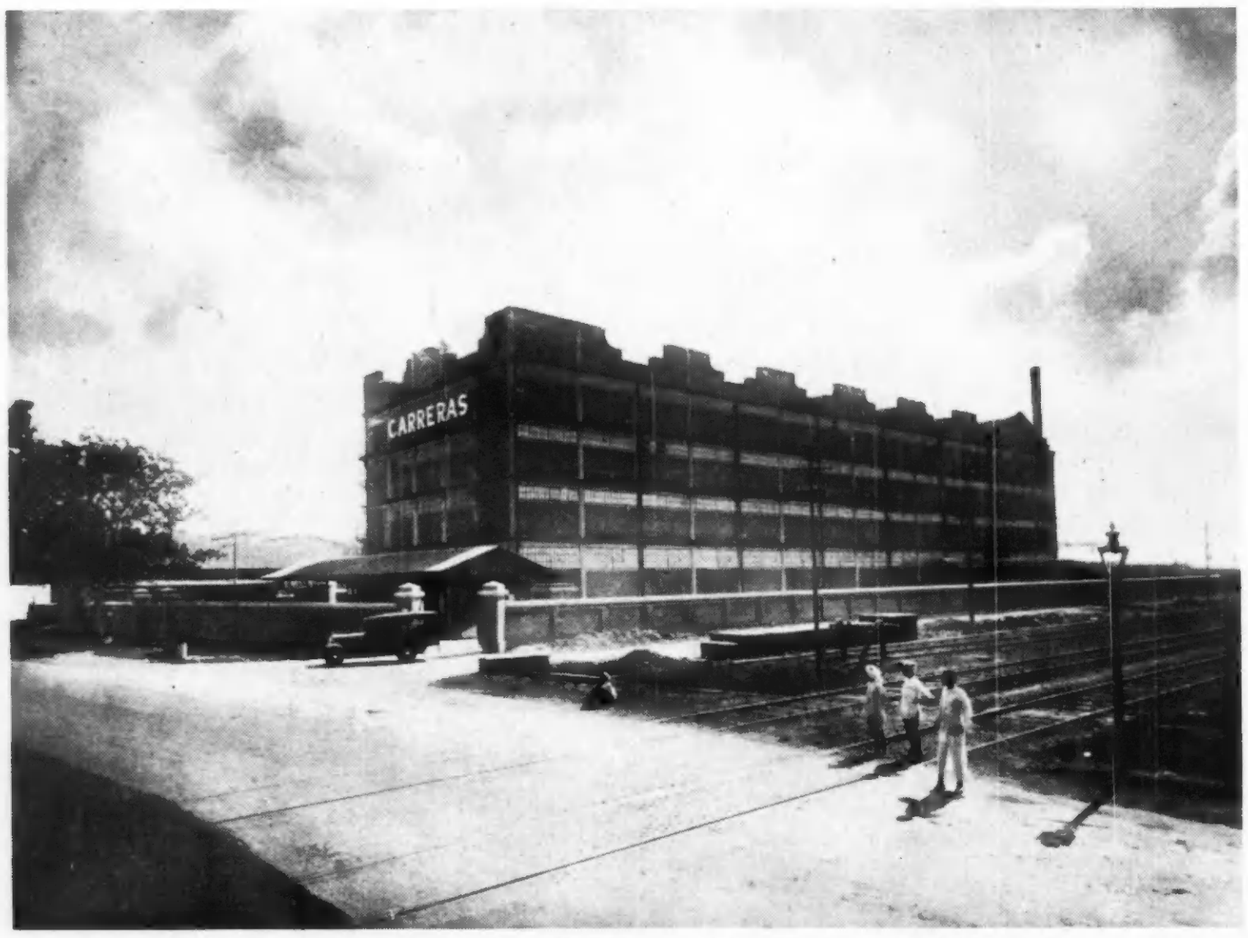


Fig. 1.—The Calcutta factory of Carreras (India) Ltd.

In addition to manufacturing space, separate departments are provided for medical and first-aid facilities and rest rooms fully equipped with lavatories for the women workers, while canteen arrangements for the different classes of labour employed are also included.

A feature of the scheme is the incorporation of an air conditioning plant which ensures a uniform and equable temperature at all times of the year. This plant was installed for reasons primarily connected with the processes of manufacture, but its beneficial effects on the health of the workers can readily be appreciated. A separate air conditioning plant is installed on each floor; as this part of the equipment is of extreme importance and interest, it will be described in more detail at a later stage in this article.

The raw material in the form of compressed Virginian tobacco leaves, imported into India in 1,000 lb. casks, enters on the ground floor where the compressed tobacco (fig. 2) is extracted from the casks, loosened, sprayed to render it supple and then left to mature for two days. The

Fig. 2.—Compressed Virginian tobacco leaves as extracted from the 1,000 lb. casks.

important process of blending comes next and is one which demands expert attention in order to maintain uniform the flavour of the finished cigarettes. The tobacco leaves are then stripped from the stalks by hand, fig. 3, Indian labour being employed for this purpose. After this process the leaf is left to mature again for a further two days and is then passed to the cutting department where the leaf is cut up by Legg cutting machines at the rate of 2,000lbs. per hour.

The cut leaf is then passed through a line of "dressers," which remove sand, dust and any pieces of stalk that have escaped detection.

Fig. 3.—Stripping the tobacco leaves from the stalks. Note the overhead ducts carrying conditioned air.

The leaf is now ready for cigarette making which is carried out by machines (figs. 4 and 5) of remarkably clever design. There are twelve of these machines, each capable of turning out 50,000 cigarettes an hour, giving a total output per working day of nearly six million cigarettes.

The leaf, cut and prepared, is fed in at one end of these machines where it is rolled and treated by strong air blasts, any residual dust or sand being sucked into containers. The rice paper, delivered from another part of the machine is printed, filled with tobacco, rolled, pasted, cut to correct size and finished cigarettes are ejected at the other end of the machine. Cork tips can also be supplied by the same machine.

The first floor of the factory is devoted to packing. The cigarettes, after passing through special conditioning rooms, are inspected for imperfections by a staff of female inspectors. They are then automatically packed into packets of ten by a battery of four packing machines capable of a total output of over 150,000 packets a day.

The packets next pass through machines which

Fig. 4.—General view in the cigarette-making department.

enclose each packet in a wrapping of "glascine" paper. Fifty of these packets at a time are packed by hand by Indian male labour into decorated tin containers which are again wrapped in "glascine" paper before being finally packed in batches of twenty tins in wooden cases ready for despatch.

Cigarettes are also packed by hand in batches of fifty into circular sheet metal containers. A circular thin metal lid is then spun on to each container by one of two rotary spinning machines. The containers next pass through an automatic soldering machine which seals the rolled joints, after which they enter a steam heated rotating drum in which the air is driven out from the containers through a small hole in the lid which has been left there for that purpose. The hot containers pass along a slowly moving belt conveyor and the small vent is soldered up by hand with a soldering iron. The containers are next rolled by a motor-driven belt over gummed labels which adhere to the outside of the tin as it is rolled over. The tins are wrapped by hand in "glascine" paper and packed in batches of ten in cardboard boxes ready for despatch.

From the foregoing description of the actual processes carried out in the factory, it will be appreciated that there was plenty of scope for the use of the electric drive and full advantage has been taken of this fact.

The incoming electric supply from the mains of the Calcutta Electric Supply Corporation is at 6,000 volts, 3 phase, 50 cycles, and is taken direct to two high tension control cubicles. Thence it is fed to two 600 kVA transformers which step down the supply to 400 volts for power and 230 volts single phase to neutral for lighting. The high tension cubicle and transformers are housed in a substation situated to the left of the main building.

A low tension flat-back switchboard, fig. 6, also installed in the substation, controls the total output to the factory. Of the eleven panels comprising this board, four control the main outgoing power and lighting feeders for the factory plant, three control the auto-transformer starting equipment of a 250 kVA synchronous condenser (referred to later), two control the incoming supply from the two 600 kVA transformers, the

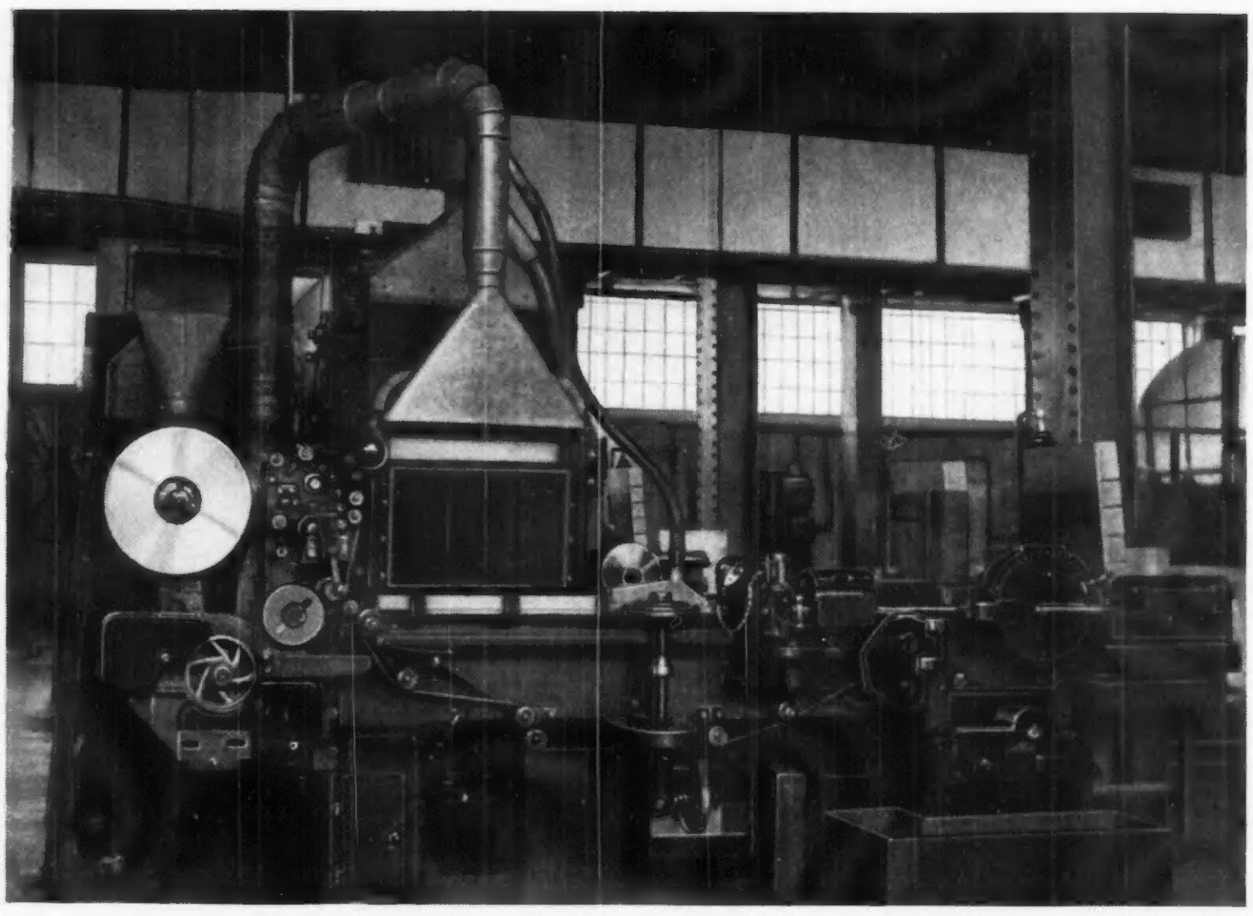


Fig. 5.—One of the cigarette-making machines. Twelve of these machines turn out six million cigarettes a day.

remaining two respectively control the outgoing feeder to a 230 h.p. synchronous induction motor driving an ammonia compressor associated with the air-conditioning plant, and two 50-volt motor-generator sets.

The 400 volt supply at the substation is conveyed to the factory by paper-insulated, lead-covered double tape armoured cable, and terminates in ironclad distribution boards. Thence the wiring runs consist of V.I.R. cable in conduit. The cables were supplied by Pirelli-General Cable Works, Ltd.

Foremost among the power requirements of the factory is that of the air conditioning plant. For a proper understanding of the installation it should be mentioned that the original building comprised

a steel frame structure having thin filling brick walls between columns and beams. The floors were of reinforced concrete supported by steel troughing, and it was therefore impossible to have a centrally located air conditioning plant from which distributing ducts could connect with the various floors. This difficulty was, however, solved by arranging a separate air conditioning plant (fig. 7) on each floor of the factory from which galvanized sheet steel air ducts convey the conditioned air to the various departments.

The construction of the building and nature of the work carried on demanded an elaborate system of automatic controls. In addition to the difficulties met with on account of the vagaries of the Calcutta climate, special arrangements had to be made in order to maintain constant conditions in all departments both day and night, irrespective of the number of persons present and fluctuations in other sources of heat and moisture gains.

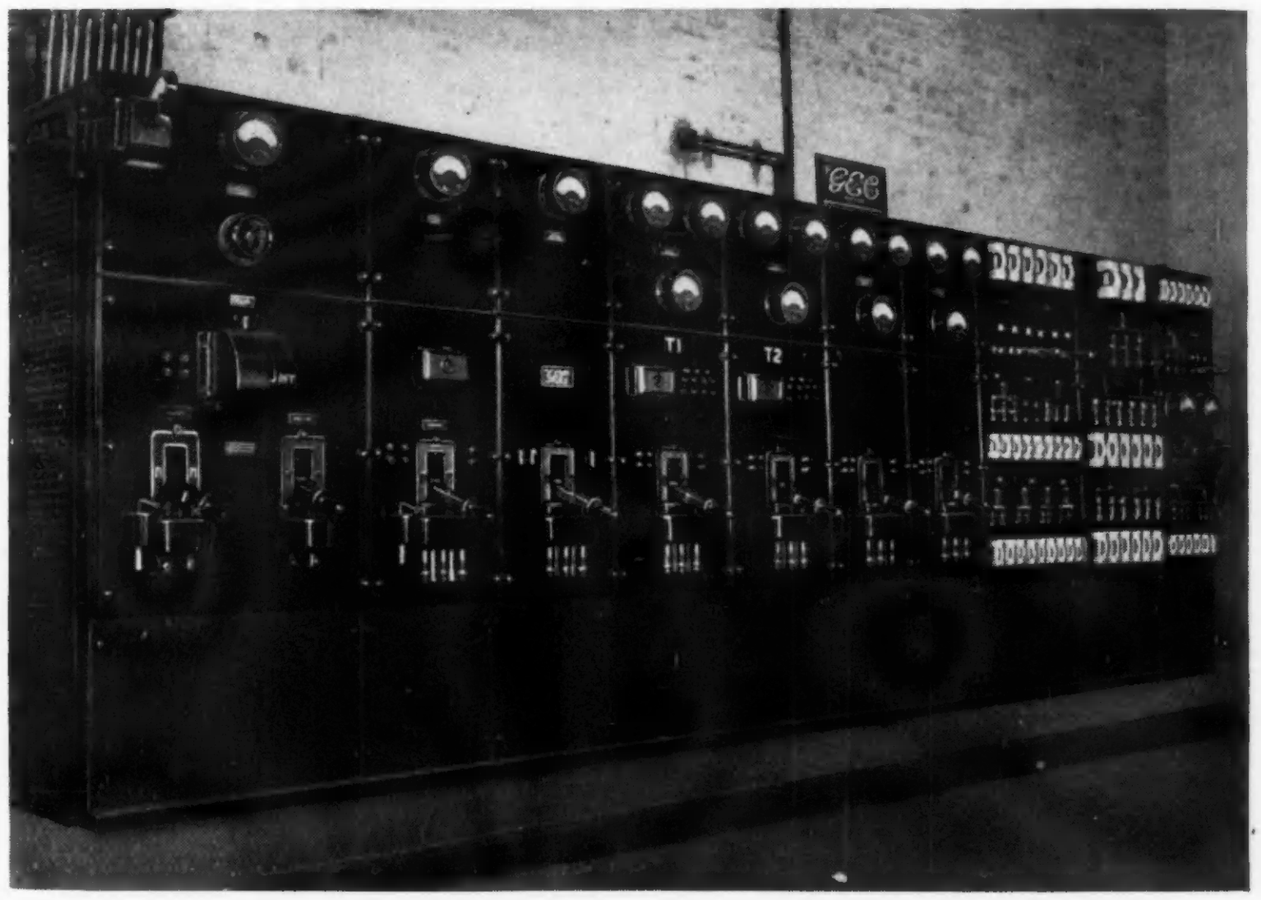


Fig. 6.—Low tension flatback switchboard installed in the substation.

At all times of the year a temperature of 85° F. is maintained throughout the factory with various degrees of humidity to suit the particular requirements of the several departments. This naturally calls for a heating plant during the cold weather and cooling equipment during the hot weather and monsoon.

The heating is provided by steam heater batteries fitted to each of the air conditioning plants and supplied with medium pressure steam from two large Cornish type boilers through thermostatically operated diaphragm valves. Cooling during the hot weather is achieved by refrigerating the water supplied to the spray nozzles of the air conditioning plants.

The power required to operate the refrigerating plant is considerable and called for very careful selection in the type of compressor used. Finally a patent sleeve valve machine of the vertical multi cylinder type, fig. 8, manufactured by H. J. West was installed. It is notable that the power consumption is only 0.8 b.h.p. per ton refrigeration, the compressor having a capacity of 230 tons refrigeration per 24 hours.

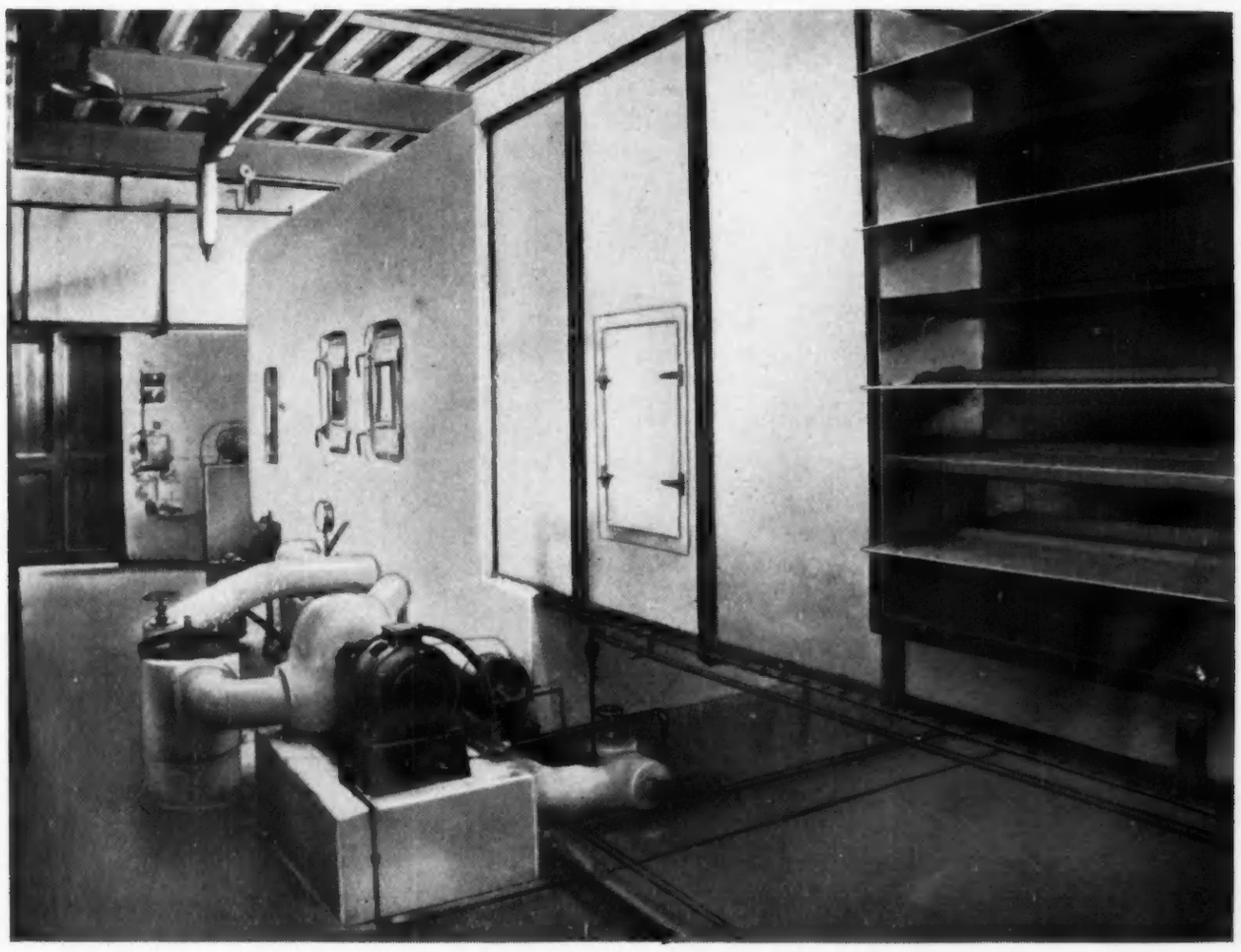


Fig. 7.—Air conditioning plant. A separate plant is installed on each floor.

The refrigerant employed is ammonia and the initial charge amounted to over one ton by weight. The hot ammonia gas discharged from the compressor is condensed back into liquid in a multitubular counter current condenser, the latent heat of condensation being carried away by a constant flow of water approximating to thirty thousand gallons per hour and supplied from three tube wells.

The liquid ammonia drains into a liquid receiver at the base of the condenser whence it flows under pressure to two multitubular evaporators. Here the ammonia is expanded into a gas again, and the heat required to bring about this change in state is taken from the

water to be cooled for the air conditioning plants.

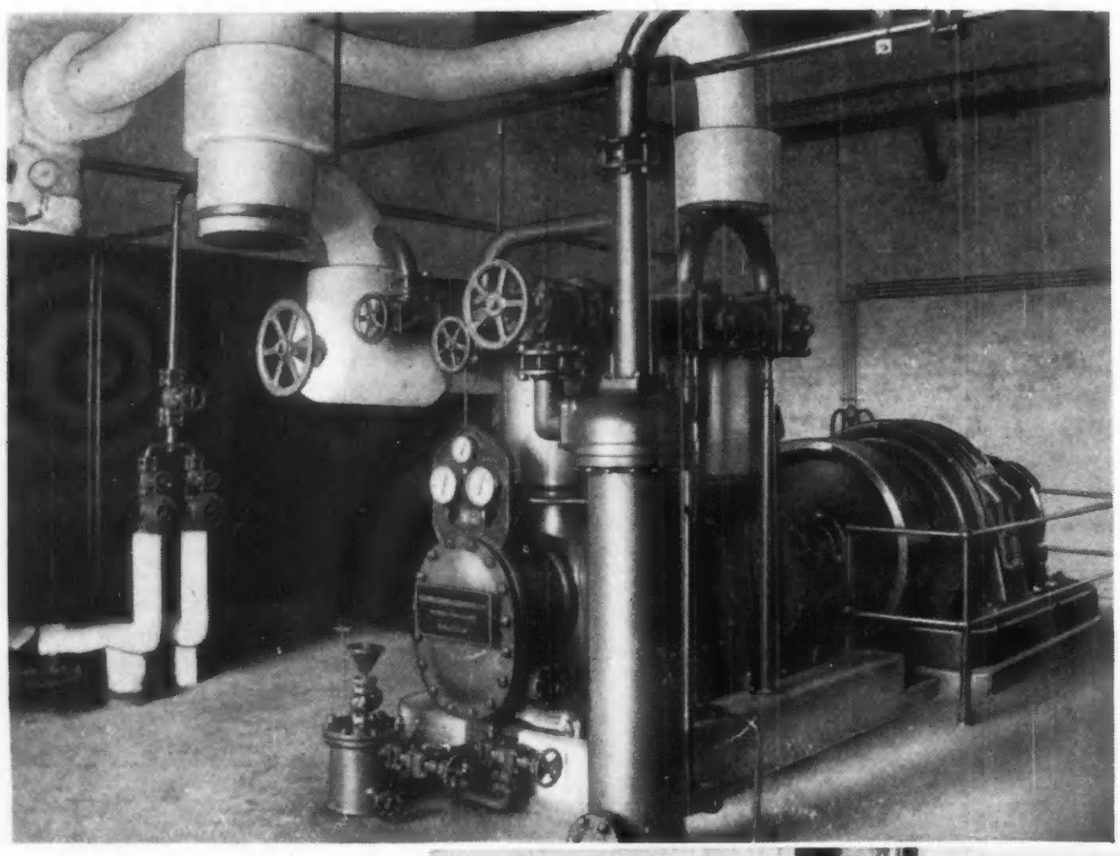


Fig. 8. — Refrigerator compressor driven by a 230 h.p. 333 r.p.m. synchronous induction motor.

The compressor is driven by a 230 b.h.p. 333 r.p.m. synchronous induction motor, fig. 9, which corrects the power factor of the entire factory during the summer. As a synchronous induction motor is a constant speed machine, the compressor capacity could not be varied in the normal way by speed reduction to meet changes in the outside atmospheric conditions. A novel system of by-passing was therefore installed which permits one or two cylinders of the compressor to idle whilst the remainder function in a normal manner.

As the compressor with its synchronous induction motor is used during the summer months only, correction of power factor during the winter had to be provided for. The Calcutta Electric Supply Corporation makes a surcharge unless the power factor is maintained not lower than .95 lagging. During the summer the synchronous induction motor driving the compressor is capable of maintaining the power factor of the entire factory at the desired figure. During the winter months a 250 kVA, 400 volt, 1,000 r.p.m. synchronous condenser (fig. 10) installed in the substation performs this service.

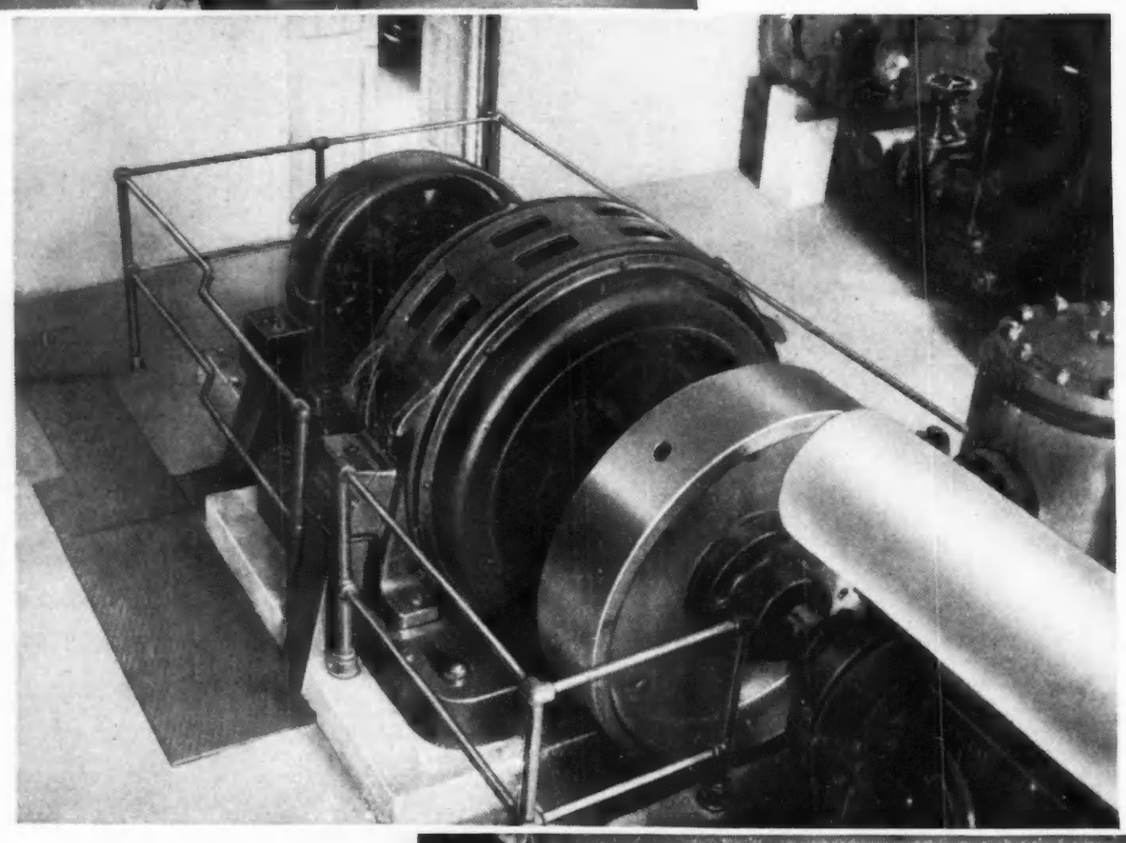


Fig. 9. — Another view of the 230 h.p. synchronous induction motor driving the compressor.

The other power requirements of the factory are those for driving pump motors, cigarette-making machines, motor-generator sets, spinning machines, etc., for all of which 75 squirrel-cage motors are installed.

In addition, power is required for three electric goods lifts, which were installed in the original building and are now used for conveying products between the four floors. The electrical equipment of these lifts was designed for a 500 volt, 3 phase, 50 cycle supply, and in order to obtain this, a 180 kVA step-up transformer, fig. 11, has been installed in the substation.

The pump motors are for providing the factory with water for process; also with drinking water. Process water is obtained from three tube wells, 300 feet deep, situated near the main building. Water from each well is pumped by a 15 h.p., 1,440 r.p.m. squirrel-cage motor to six storage tanks installed on the top of the factory, and having a total capacity of 60,000 gallons.

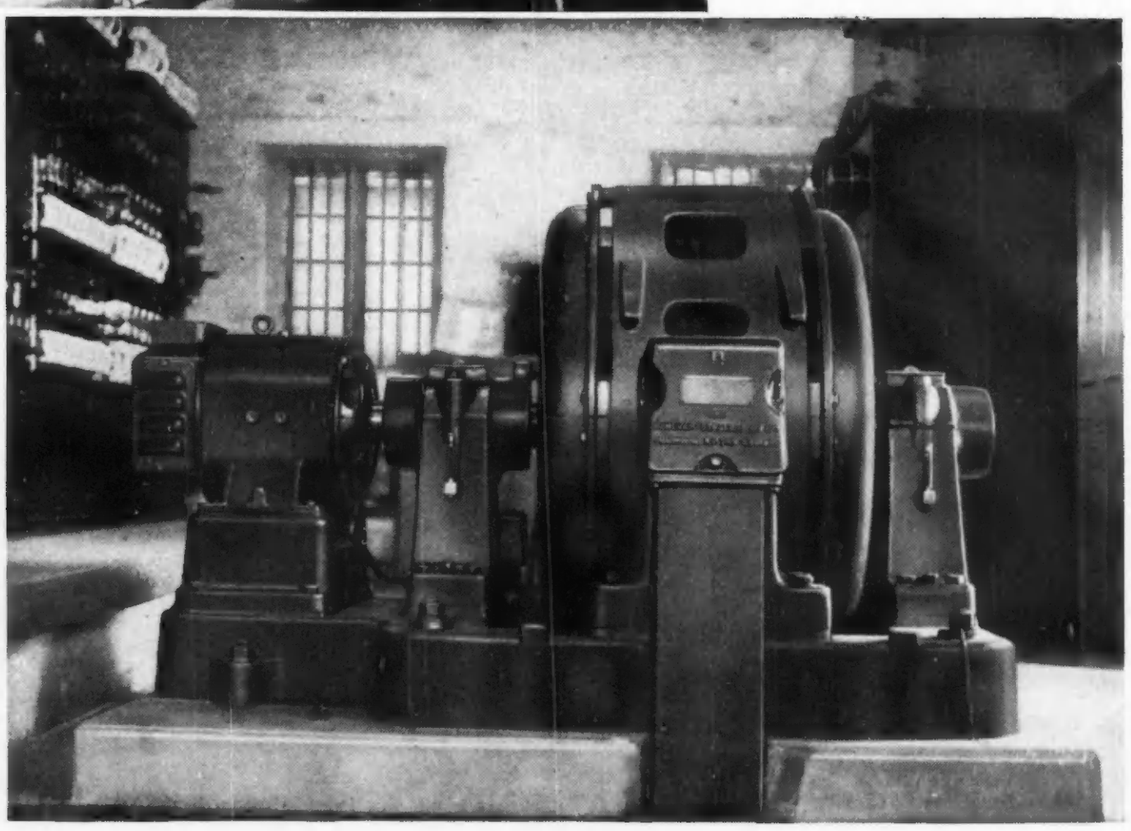


Fig. 10.—250 kVA 1,000 r.p.m. synchronous condenser in the substation.

The water in the tanks is protected from the tropical sun by an asbestos-tiled roof. The pump motors are controlled by float-operated contactor gear which automatically maintains the required amount of water in the tanks.

For the drinking water supply three 3 h.p., 3,000 r.p.m. motor-driven pumping sets are provided, and are installed in the compressor room.

Eight of the twelve cigarette-making machines are each chain-driven by a $2\frac{1}{2}$ h.p. totally enclosed squirrel-cage motor running at a speed of 960 r.p.m., while the remaining four machines, which are of a different make, are each chain-driven by a 3 h.p. motor. These motors supply the whole of the power required for the many intricate operations the cigarette-making machines carry out. An electric heating element is embodied in each of these machines, current for which is supplied by the two 50-volt A.C.—D.C. motor-generator sets previously mentioned (fig. 11).

A total of fifteen motors ranging from $\frac{1}{2}$ to 3 h.p. in capacity are used to drive, through belting, the cutting, dressing, packing, wrapping and spinning machines.

For the air-conditioning plant, apart from the compressor motor which has already been mentioned, several squirrel cage motors are used for driving the circulating fans, ammonia evaporators, spray pumps, etc., and these range in size from $7\frac{1}{2}$ to 15 h.p. at speeds of 950 to 1,450 r.p.m.

The control gear for the motors comprises (in the case of machines up to 5 h.p.) push-button operated direct-to-line starters, while in the case of motors above this capacity, manually operated star-delta starters are employed.

In conclusion, the author wishes to thank the Director and Chief Engineer of Carreras Ltd., London, Mr. W. H. Louden, for his permission to publish this article, and to Mr. M. C. Taylor, Chairman and Managing Director of Carreras (India), Ltd., for his assistance in its preparation.

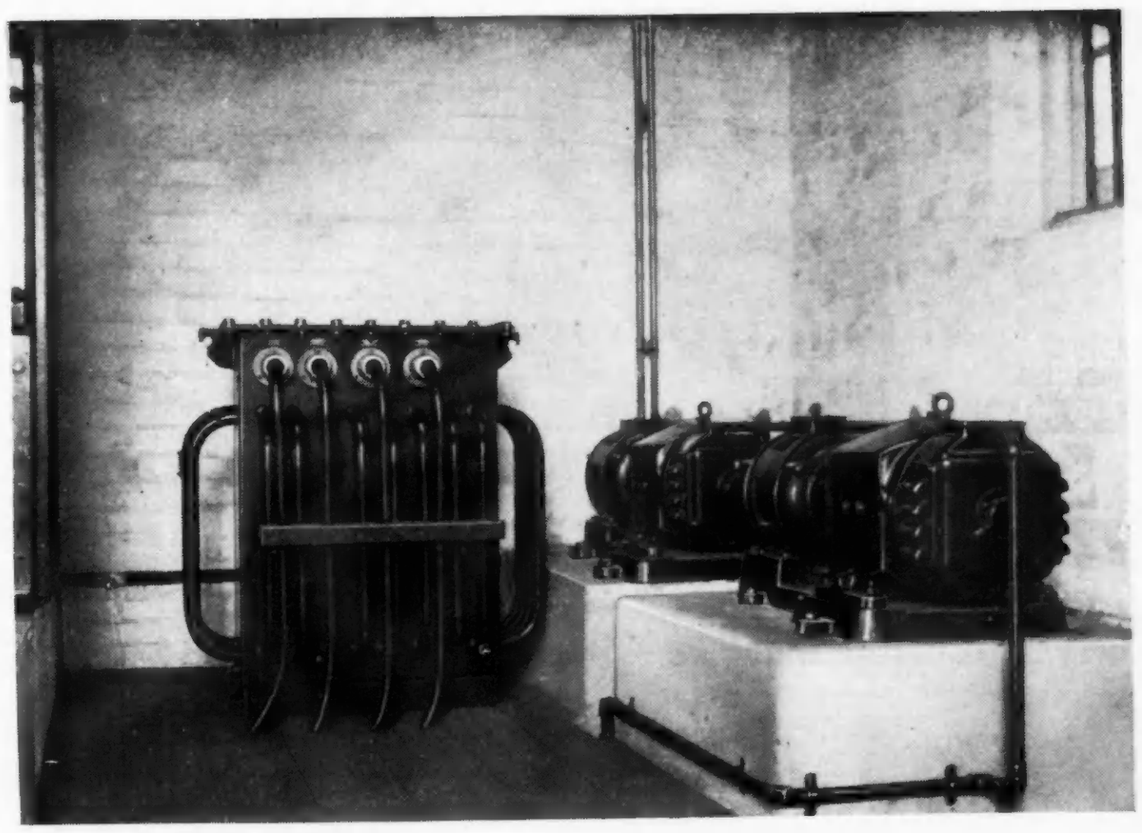
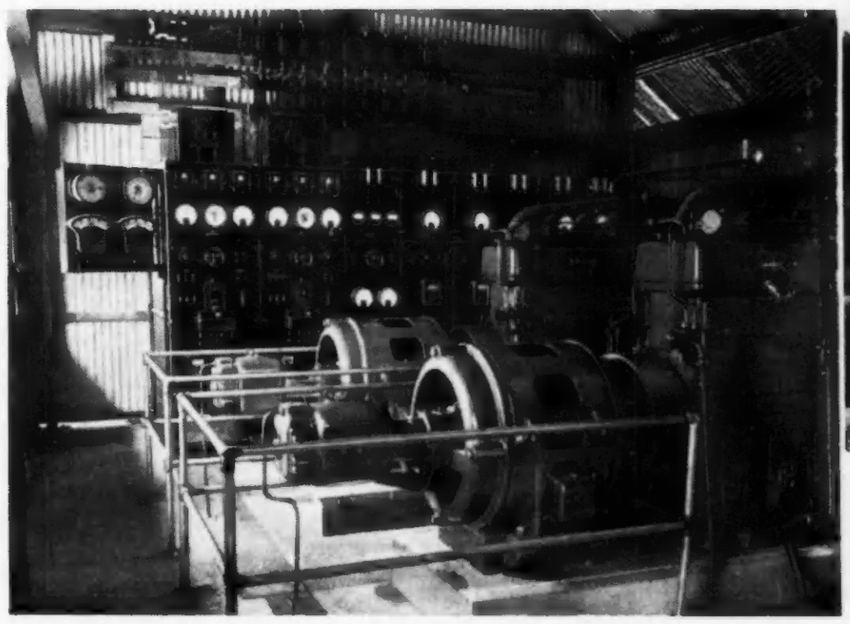


Fig. 11.—Transformer and motor-generator sets supplying power for lifts and heaters in cigarette-making machines.

Electric Lighting for Brunei Town, Borneo.

An interesting electric power installation has recently been completed by the G.E.C. in Borneo for the complete electrification of the town of Brunei and comprises a small power station, an overhead distribution network and the wiring of the houses for electric lighting and power.



The power station containing two 40kW 230/440 volt, 3 phase, 50 cycle alternators each coupled to a 70 b.h.p. oil engine, with a control switchboard in the background.

Part of the overhead line with a pole mounting transformer stepping up the supply to 2,000 volts for feeding to the Residency. The hut contains a circuit breaker.

The Electrometer Triode and its Applications.

By G. W. WARREN, B.Sc.

Research Laboratories of The General Electric Co. Ltd., Wembley, England.

The thermionic electrometer triode is being increasingly used by workers in many branches of science. In this article the author describes the main features in the design of this instrument, and gives the characteristics and operating conditions. The more important applications are briefly discussed.

DURING the past few years there have appeared on the market, in England, America and on the Continent, several types of thermionic valves, known as electrometer valves, the essential characteristic of which is an extremely low value of grid current when operated under certain conditions. The Osram electrometer triode, type "T," which was first developed towards the end of 1930, and to which many improvements have since been made, has proved of great value to many workers in laboratories and factories for the accurate measurement of electrostatic potentials and very small electric currents such as, for example, potentials on glass electrodes, photoelectric currents and ionization currents. It is hoped that this article may assist those to whom the electrometer triode would be a useful instrument, but who perhaps are not fully familiar with the possibilities and limitations of the thermionic valve.

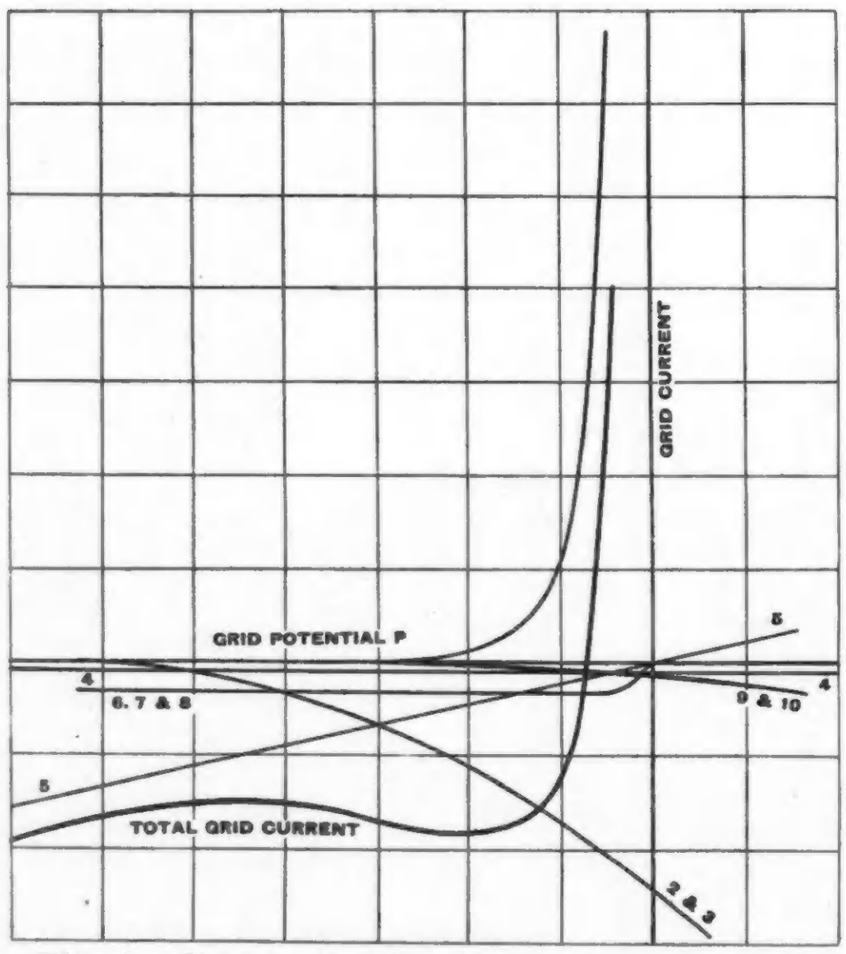


Fig. 1.—Curves showing general nature of grid current produced by various causes.

THE THERMIONIC VALVE AS A VOLTMETER.

Apart from its main uses in generating, rectifying and amplifying oscillating currents, the thermionic valve has many secondary but important applications. Among these, its use as a valve voltmeter is probably the best known. In the simplest application, the voltage to be measured is applied between the grid and cathode of a triode, and the anode current, which with constant anode voltage is a unique function of the grid potential, is measured. A calibration of the valve determines the relationship between anode current and grid potential. There are several modifications to this arrangement for different purposes, but these will not be considered in detail here.

The main advantage of the valve voltmeter over the electromagnetic types is the very high impedance of the grid cathode-circuit when the grid is at a negative potential with respect to the cathode and the consequent small load imposed on the source of potential to be measured.

In the standard types of triode as used in radio receivers the grid cathode impedance may be as high as 10^8 or 10^9 ohms, but rarely exceeds this value; and even if special precautions are taken in the manufacture it is difficult to obtain values much greater than 10^9 ohms over a wide range of grid voltage, so that valves of standard design cannot, without elaborate compensating devices, be employed to replace electrostatic instruments such as electrometers or electroscopes.

The electrometer triode valve was designed with a view to removing this limitation and to provide an alternative to the more usual forms of electrometer which, as is well known, are very delicate and sometimes call for elaborate precautions and adjustments.

THE CAUSES OF GRID CURRENT IN A VALVE.

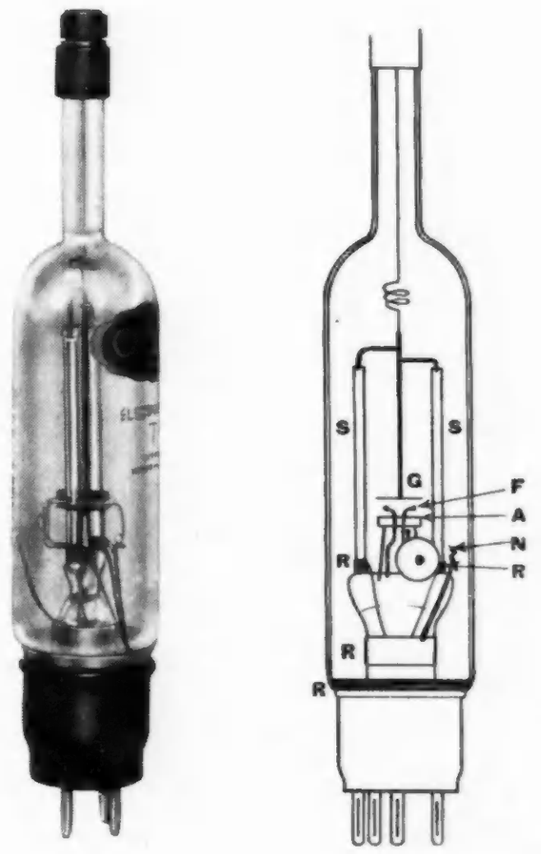
The chief possible causes of grid current in a thermionic valve operated at a negative grid potential are the following :—

1. Electrons passing from the cathode to the grid.
2. Positive ions produced in the residual gas.
3. Positive ions produced on the anode surface by electron bombardment.
4. Positive ions from the anode.
5. Poor insulation between grid and other electrodes.
6. Primary electron emission from the grid.
7. Positive ions from the cathode.
8. Photoelectric emission from the grid.
9. Secondary emission from the grid due to positive ion bombardment.
10. Relatively high velocity secondary electrons from the cathode due to positive ion bombardment.

The general nature of these currents is shown in fig. 1, from which it is clear that item 1 above is eliminated if the grid is operated at a potential more negative than P volts with respect to the cathode or negative end of the filament. The value of P is a function of the initial velocity of the electrons from the cathode and the contact potential difference between grid and cathode surfaces. Now, if the anode potential is considerably less than the ionisation potential of the residual gas, item 2 will be eliminated and 3 will be reduced to a very small value. Indirectly, item 4, which is a function of anode temperature, will also be reduced, and therefore 9 and 10 which are caused by 3 and 4 will assume negligible values. Primary electron emission from the grid (6) may be eliminated by designing this electrode so that it operates at a very low temperature, and the emission of positive ions from the cathode (7) may be eliminated by using a dull emitting filament or by introducing an extra electrode which is maintained at a positive potential adjacent to the cathode. This latter method has been adopted in the American valve type F.P.54.[1] It has been found, however, that from a dull emitting filament rated at 0.1 watt, and the temperature of which does not exceed 950°K., the positive ion emission is certainly less than 10^{-17} amps., and the additional complexity of the space charge grid has been avoided. We are now left with items 5 and 8. The photoelectric emission from the grid is reduced by the use of a dull emitting filament and by operating the valve in the dark. A suitable treatment of the grid and anode surfaces still further reduces 8 and 3. The elimination of the leakage current is accomplished by a suitable design and choice of insulating materials.

CONSTRUCTION OF THE ELECTROMETER TRIODE.

All the above factors have been carefully considered in the design of the Osram electrometer triode type "T," with the result that it has been found possible to reduce the total residual grid current to less than 10^{-15} amp. while retaining reasonable sensitivity. An illustration and sectional drawing of this instrument are shown in figs. 2a and 2b. The anode (A) and filament (F) are mounted on a glass pinch, and the control electrode or grid (G)



(a) (b)

Figs. 2 (a).—General view, and (b) sectional diagram of Osram electrometer triode type "T."

which is in the form of a flat plate, is supported from two pillars (S) of special high resistance glass sealed to the pinch, the grid lead being taken to a terminal through the end of a stem, also of high resistance glass, sealed to the top of the tubular bulb. The glass used for the bulb and stem has been so chosen as to have very low surface leakage properties, and is not affected by exposure to the atmosphere over long periods. The resistance of the grid circuit is of the order 10^{17} ohms. A high speed diffusion pump is used for evacuating the valve, and the vacuum is still further improved by dispersing a metallic "getter" in the lower part of the bulb. Great care is taken to ensure that the getter surface does not spread over the upper portion of the bulb and the insulating pillars which carry the grid. Internal and external guard rings (R) are provided which are connected to a pin in the base of the electrometer. A nickel steel spring (N) is welded at one end to the internal guard ring, the other end being held back to the anode support wire by a fine nickel wire which, after gettering and immediately before sealing-off the valve from the pump, is burnt out, so that the spring is released to make contact with the getter surface. The guard rings and getter surface may be maintained at earth potential, or preferably at the mean operating grid potential, thus obviating the risk of stray charges accumulating on the glass and getter

surfaces due to the various potentials of the electrode supports, and ensuring stability of characteristics.

CHARACTERISTICS.

The electrical characteristics of the electrometer triode are as follows :—

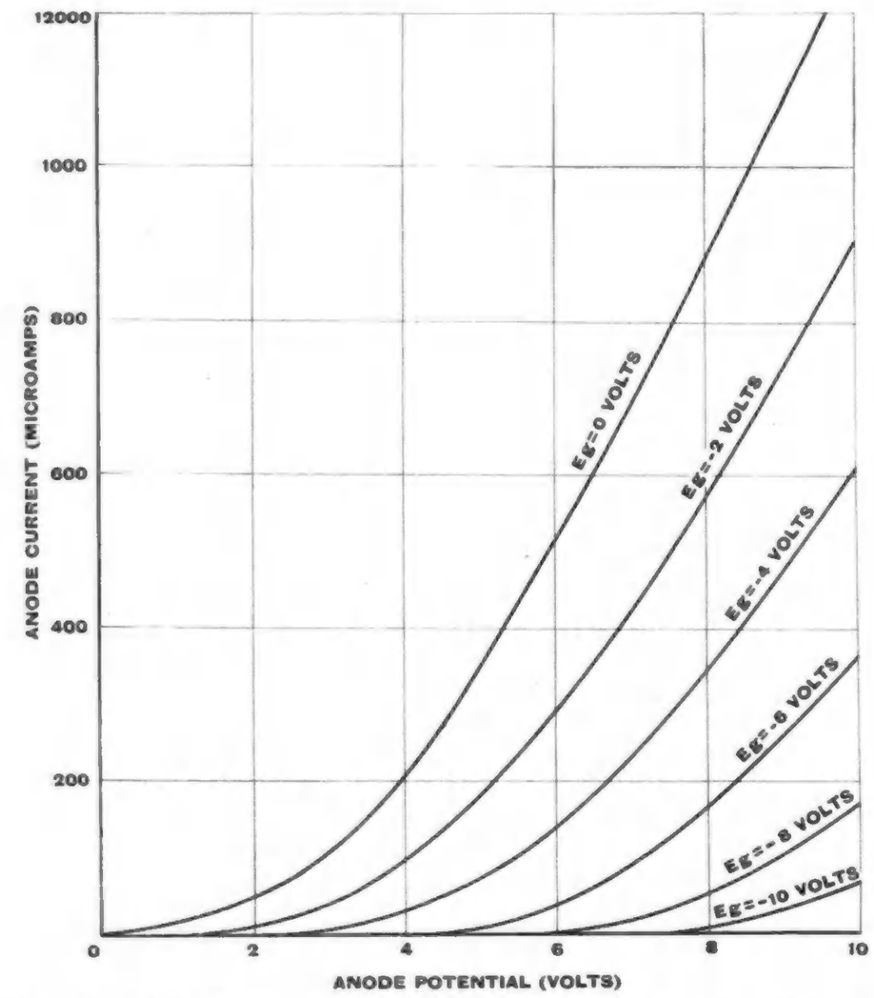


Fig. 3.—Anode current plotted as a function of anode potential.

Filament 1.0 volt, 0.1 amp.

Anode 3—10 volts.

Mutual conductance with anode + 4 volts, grid −2 volts = 40 micro-amps per volt.

Capacity of grid to other electrodes = 2.4 micro-microfarads.

Figs. 3 and 4 show the anode current plotted as a function of anode potential and grid potential

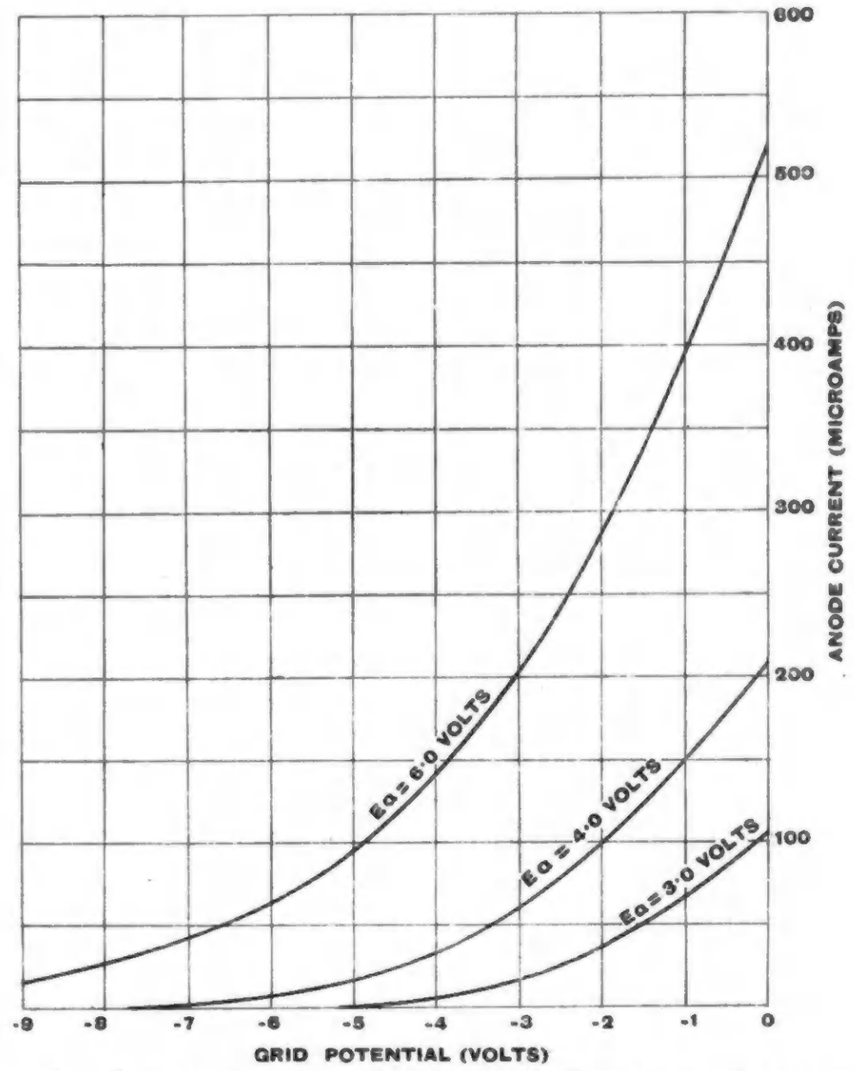


Fig. 4.—Anode current plotted as a function of grid potential.

respectively, while figs. 5, 6 and 7 show the grid current characteristics at three values of anode voltage.

The low filament current and low anode voltage for which the electrometer is designed have a distinct practical advantage, particularly in portable

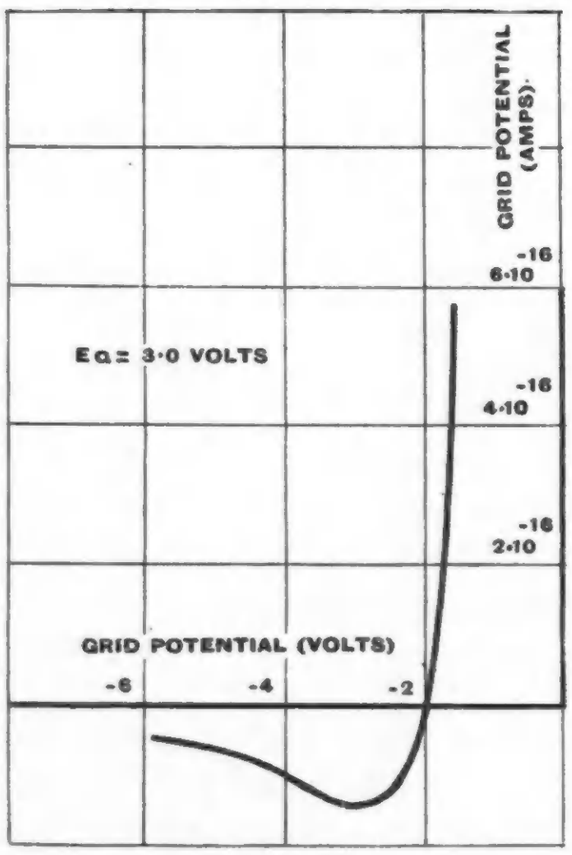


Fig. 5.

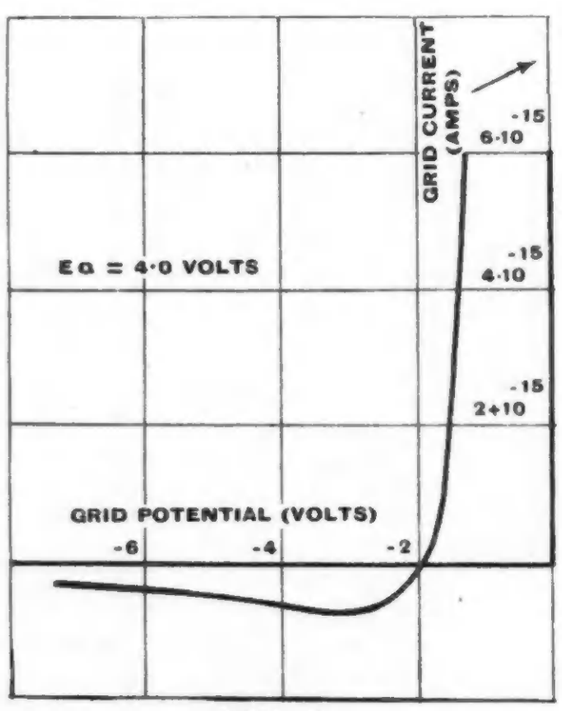


Fig. 6.

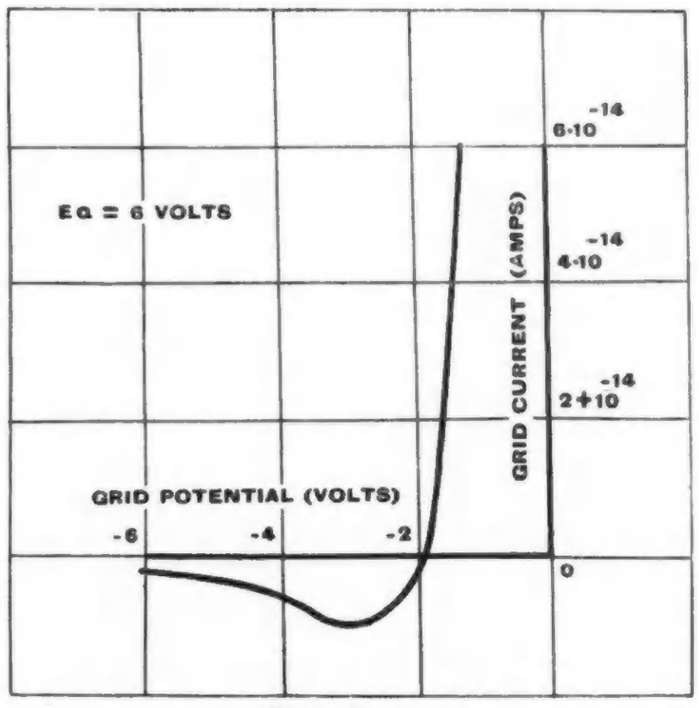


Fig. 7.

Figs. 5, 6 and 7.—Curves showing grid current characteristics at three values of anode voltage.

Mutual conductance with anode + 6 volts, grid −2 volts = 80 micro-amps per volt.

Insulation resistance between grid and other electrodes $> 10^{17}$ ohms.

apparatus, it being a relatively simple matter to maintain steady filament and anode currents from a low voltage accumulator of about 60 ampere hours' capacity. The stability so obtained is for many pur-

poses sufficient without any further precautions. Advantages over the more usual forms of electrometer are comparative robustness, low input capacity and greater sensitivity and stability. With the anode at 4 volts and the grid at −2 volts, the drift in anode current after the first twenty minutes' running does not exceed 0.04 microamps per hour.

Although this instrument is rated at a maximum anode potential of 10 volts, the actual anode voltage employed will depend on the particular purpose for which the instrument is used. It will be seen from figs. 5, 6 and 7 that the residual grid current increases rapidly with anode voltage. With the anode at 9 volts the maximum grid current is of the order 10^{-13} amp. When high mutual conductance is more important than very low grid current the higher values of anode potential may be employed with advantage, but if it is required that the grid current shall be as low as possible, then it is essential that the anode potential shall not exceed 4 volts. Some idea of the magnitude of the grid current may be obtained from fig. 8, from which it will be seen that with the anode at 3 volts, if the grid is charged to a potential of −6 volts and left free, it takes over 30 hours for the potential to rise to the final floating grid potential of about −1.9 volts. At this potential the grid current in the valve is zero, or, more accurately, the electron and positive ion components of current balance one another exactly, so that the grid-cathode system imposes no load on any circuit across which it is connected. Over a small range of about 0.1 volt in the neighbourhood of this point, the grid current does not exceed 2.10^{-17} amp., the low frequency A.C. impedance being about 2.10^{15} ohms. In any thermionic valve, of course, a similar point does exist at which the grid current becomes zero, but in ordinary types of valve the grid impedance at the point does not exceed 10^{9} ohms, so that there is only a very small range of grid potential over which the grid current is negligible, and it is doubtful whether the characteristics would be sufficiently stable for this "floating grid potential" to be utilised except in a limited number of cases.

GENERAL METHODS OF USE.

The electrometer may be used in several ways for the measurements of potentials, very small electric charges and currents, such as photoelectric or ionisation currents, or high resistances, the method adopted depending on the magnitude of the quantities to be measured.

For many purposes it is safe to assume that a grid current of 10^{-15} amp. is sufficiently small for it to be entirely neglected, and the triode may be operated with the anode potential not exceeding +4 volts over a wide range of grid potentials greater than 2 volts negative with respect to the negative end of the filament.

Electrostatic potentials from 0.1 millivolt to 6 volts applied directly between grid and filament may be determined by measuring the change produced in the anode current, which may be measured by a microammeter or galvanometer, the steady anode current being, if necessary, balanced out. Alternatively, a "null" method may be used by including in the grid circuit in series with the source of potential to be measured, a potentiometer by means of which the anode current is restored to its original value after being changed by the unknown potential on the grid.

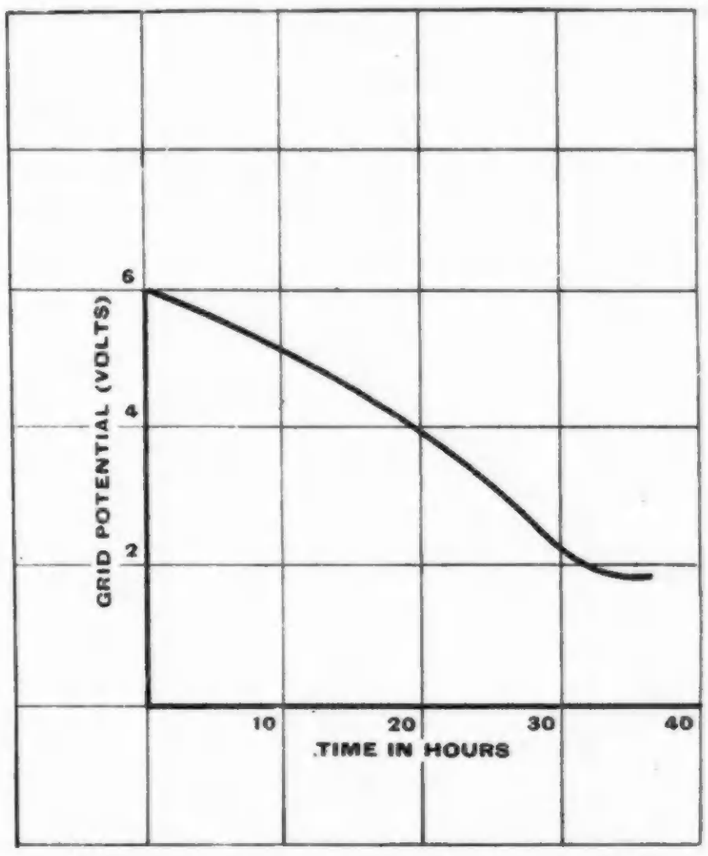


Fig. 8.—Curve showing rate of change of grid potential with grid "free." (Anode + 3 volts)

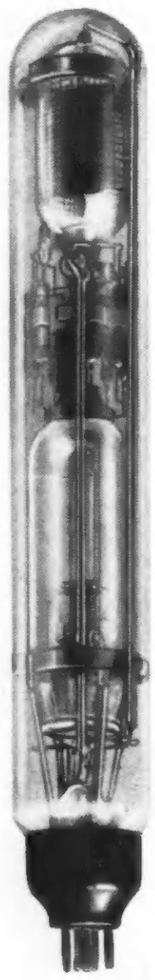
Similarly, small currents may be measured by impressing on the grid of the electrometer the potential drop across a known resistance carrying the current whose value is to be determined.

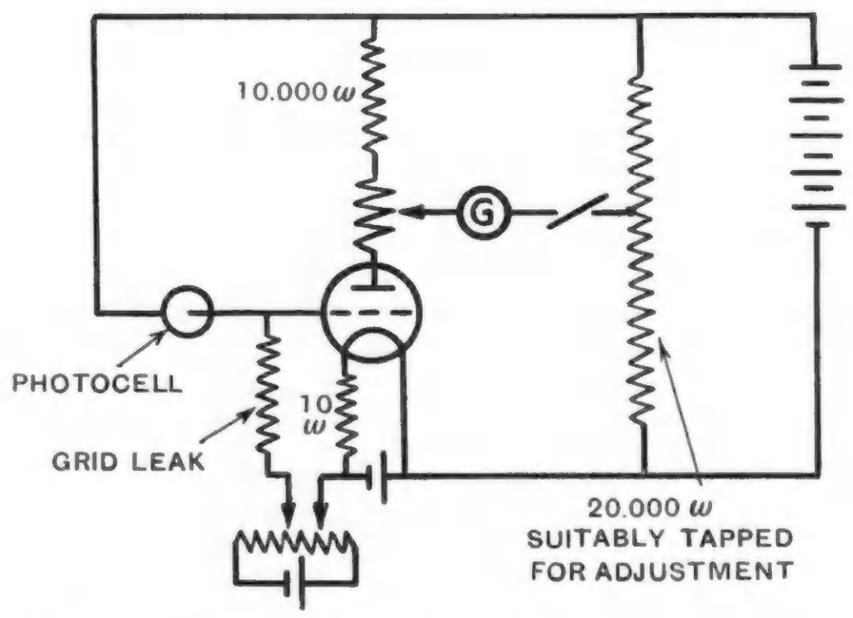
For measuring alternating currents or potentials the electrometer may be the first valve of a resistance-capacity coupled amplifier, the output being rectified or measured by an A.C. instrument. The valves following the electrometer must have stable characteristics, but not necessarily very high values of input impedance. It should be mentioned that the input impedance of the electrometer triode at 1,200 kilocycles per second exceeds 100 megohms, but its exact value has not been determined.

APPLICATION TO PHOTOMETRY.

In some apparatus designed at the Research Laboratories of the G.E.C. for photometric measurements, two electrometer triodes were arranged to form two arms of a Wheatstone bridge, the other arms being the impedances in the anode circuit, and the current produced in a photocell was passed through a high resistance between grid and filament of one of the electrometers.[2] In this way any "drift" due to variations

in battery voltage was eliminated. More recently the apparatus has been modified, in that only one electrometer is used, resistances forming the other arms of the bridge. The electrometer, photo-cell and grid resistance are mounted together in an evacuated glass bulb. In this way the risk of leakage currents in the photocell-grid circuit due to moisture on the outside surface of the electrometer is entirely eliminated, and the apparatus can be used with safety in a humid atmosphere such as might be





Figs. 9. and 10.—Photocell electrometer triode unit and circuit diagram.

encountered in a factory. The accompanying photograph (fig. 9) shows the photocell-electrometer triode unit, while fig. 10 is a circuit diagram of the apparatus.

MEASUREMENT OF HYDROGEN-ION CONCENTRATION.

Perhaps one of the most important applications of the electrometer triode has been the measurement of glass electrode potentials in the determination of Hydrogen ion concentration values. It affords a convenient method for the rapid determination of the small potentials on the high resistance glass electrode, and a considerable amount of work on the subject has been carried out during the past few years. For details of the methods employed, reference should be made to the original papers.[3, 4, 5, 6, 7, 8] In one of these papers[6] a method of compensating for small fluctuations in battery voltages is described, and the essential features of the circuit are shown in fig. 11. A current of exactly 0.1 amp. from a 12 volt battery E is passed through the potentiometer A, filament, and resistances B and C in series, this current being measured by means of a standard cell (1.0183 volts) in series with the galvanometer across the standard resistance B (10.183 ohms) when the double pole switch S_1 is in position 1. The grid bias is supplied by a tapping on the calibrated potentiometer A, and the anode potential is tapped off the resistance C. With the switch S_1 in position 2, switch S_2 being in position 1, the anode current is balanced out by adjusting the resistance D. Then with the switch S_2 in position 2 the potential to be measured is applied to the terminals T (negative pole to grid). The anode current falls and may be restored to its original value by means of the potentiometer A. The values of the resistances in the circuit have been chosen so that the instrument is self-adjusting for fluctuations in battery voltage.

SOME OTHER APPLICATIONS.

Other purposes for which the electrometer triode has been used include the measurement of ionisation currents [9, 10, 11] the determination of high resistances,[12] and for studying the piezo-electric effect in crystals.

OTHER METHODS OF USE.

In the applications described above it has been assumed that the residual grid current in the triode is negligible compared with the currents to be measured. In many cases in practice this assumption is justified; but it may not always be so, and the use of the electrometer triode is not limited to these cases. It is possible to measure currents of the order 10^{-15} amp. or less with reasonable accuracy. Several methods present themselves. The anode may be operated at 3 volts and one of the methods mentioned above may be used. From fig. 5 it will be observed that the maximum grid current is now only 1.5×10^{-16} amp., but the sensitivity is reduced somewhat and the grid voltage range is limited. In another method the grid of the electrometer is charged to a negative potential with respect to the filament; the current to be measured is then

passed into the grid circuit in a direction which will make the grid become more positive, and the rate of change of grid potential is determined from observation of the rate of change of anode current, the valve having previously been calibrated. A curve similar to A (fig. 12) will be obtained from which the current flowing in the grid circuit can be calculated if the capacity of the input circuit is known. Similarly, by obtaining the curve B when the unknown current is not flowing, the grid current of the valve may be determined. From the difference between A and B the value of the unknown current may be calculated.

In another method two electrometer triode valves may be used in a Wheatstone bridge, as in the apparatus described above for photometric measurements. By the addition of capacity or resistance between grid and filament of one of the valves, the residual grid currents may be made identical, so that if both grids are charged to a potential V_0 and then isolated, the grid potentials will change at the same rate, and no galvanometer deflection will be observed as long as this condition is fulfilled. If now the small current to be measured is applied to the grid of one of the valves, its

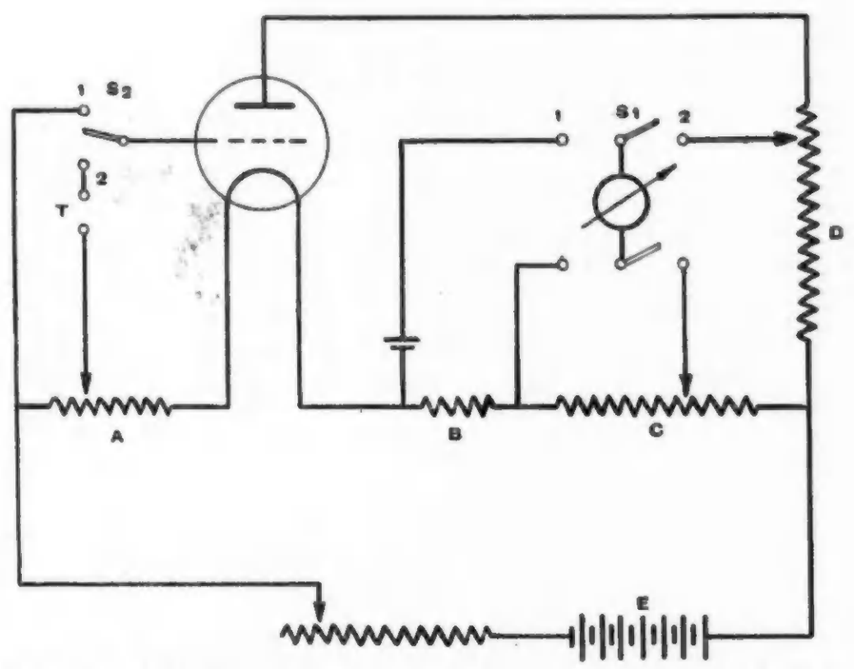


Fig. 11.—Method of compensating for small fluctuations in battery voltages.

magnitude is determined by the rate of increase of deflection of the galvanometer.

DESIGN OF APPARATUS INCORPORATING ELECTROMETER TRIODE.

In conclusion, one or two hints on precautions to be taken in designing apparatus to include an electrometer triode valve may not be out of place. The electrometer is rather microphonic by comparison with valves of standard type. This disadvantage is unfortunately inherent in the design, and could not easily be overcome without modifications which would increase the grid current and input capacity of the valve. If, however, the electrometer is mounted in a good anti-microphonic holder, no difficulty will be experienced due to variations in anode current resulting from mechanical

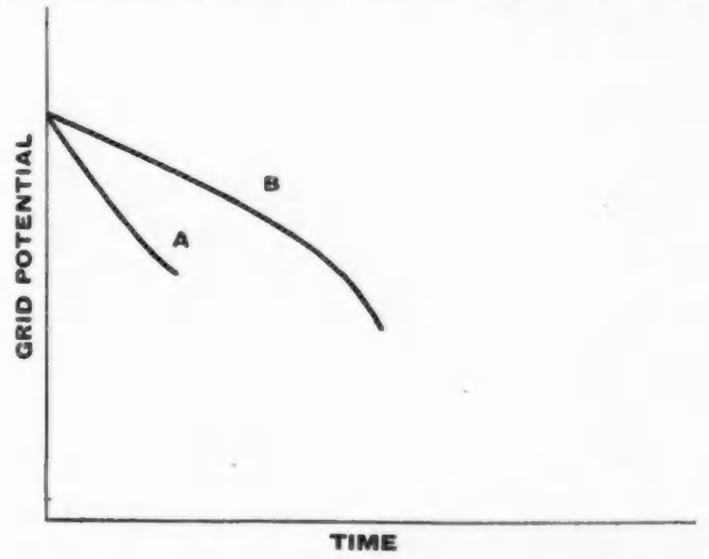


Fig. 12.—Curves obtained in one method of measuring very small currents.

vibration such as might be encountered in a factory where machinery is running.

It is, perhaps, hardly necessary to mention that, whatever method of using the electrometer triode is adopted, the valve and input circuit should be carefully screened, and the screen earthed through a low resistance conductor. This is particularly important when the valve is being operated at the floating grid potential, as small stray charges will affect this potential, and also any oscillating currents picked up in the grid circuit will be rectified and alter the anode current. Complete electrical screening also serves the purpose of preventing light from falling on the electrode surfaces and causing variations in grid current due to photoelectric emission.

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VEREENIGING

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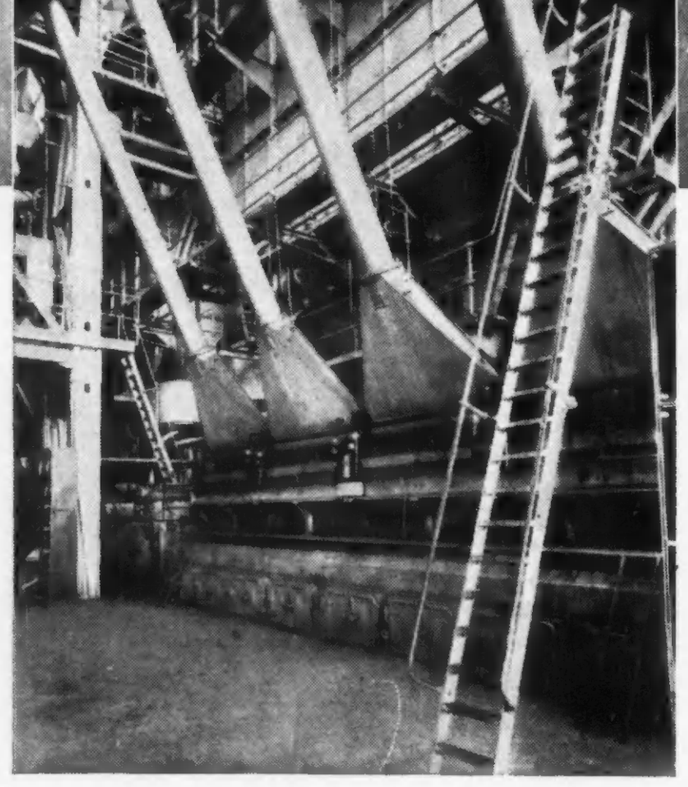

These stokers are the widest B. & W. travelling grate stokers **in operation,** but are exceeded in size by eight stokers ordered in 1934—each being 33' 0" wide x 20' 0" long—for the Klip Generating Station, owned by The Electricity Supply Commission of the Union of South Africa and operated by the Victoria Falls & Transvaal Power Co., Ltd., who now operate or have on order a total of 140 B & W Boilers and 20 Bailey Furnaces.

By courtesy of South African Railways and Harbours

IN 1931, four B. & W. Boilers were ordered, each for a normal evaporation of 160,000 lbs. of steam per hour at 752° F. with a safety valve load of 258 lbs. per sq. in. These boilers are fitted with B. & W. forged steel return bend economisers, B. & W. plate type air heaters, and are fired with B. & W. Style 28 Stokers 32' 0" wide x 20' 0" long in Bailey Furnaces. The contract included the boiler-house building and all accessories. An additional boiler duplicating the above was ordered in 1934.

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